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A
S U R V E Y
OF
EXPERIMENTAL
R PHILOSOPHY.

VOL. II.

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A
SURVEY

OF

EXPERIMENTAL

PHILOSOPHY

VOL. II.

A
S U R V E Y
OF
EXPERIMENTAL
PHILOSOPHY,

Considered in its
PRESENT STATE OF IMPROVEMENT.

ILLUSTRATED WITH CUTS.

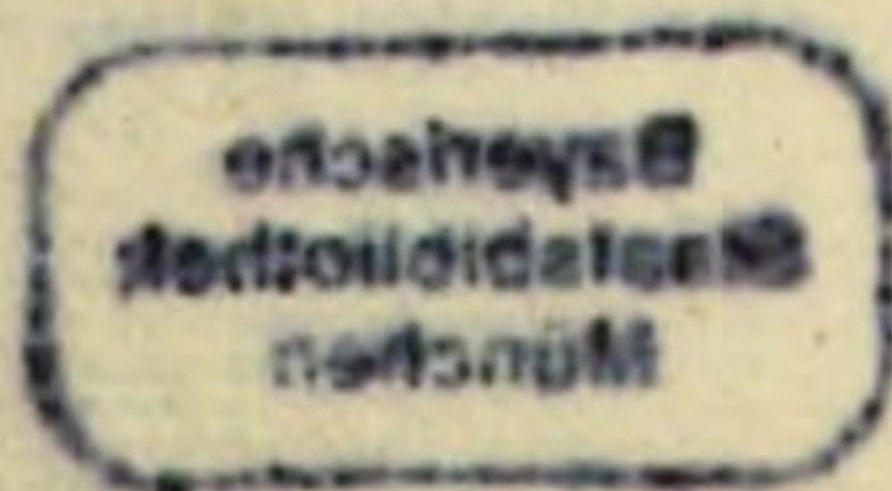
VOL. II.

By OLIVER GOLDSMITH, M. B.

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ib. l. 8, read *Fig. 49*.

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SECOND VOLUME.

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A SURVEY

A
S U R V E Y
O F
E X P E R I M E N T A L
P H I L O S O P H Y.

B O O K II.

C H A P T E R I.

Of the Air, and some of its Properties.

HAVING just calculated the resistance given by the air to bodies in motion, this naturally leads us to consider the nature and properties of the air itself. It was the method with the natural philosophers that just succeeded the ages of obscurity to divide the subject

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of

of their investigation into as many parts as they supposed there were elements; namely, earth, air, water, fire. We know nothing of the elements of which bodies are composed; but as there is nothing absurd in the order they have used, and as the parts will be more easily explained thus, we beg leave to adopt a method, which, though less modern, will be found more perspicuous.

A GREEK philosopher, when some wranglers asked him for a definition of motion, got up and walked; he shewed them the thing, which was the best definition he could give. Were we asked in the same manner what is air, we should refer the querist to his experience alone for information. Animals breathe the air, birds fly upon it, fire burns in it, sounds float in it; in short, the best definition of this substance is the enumeration which we are about to give of its properties.

How-

HOWEVER the form of air may escape our sight, yet its substance strikes all the rest of our senses; the bladder when filled with air is very different from the same when empty, and then resists pressure with great force. All places on the surface of the earth are replete with air, we find it in the bottom of the deepest caverns, and upon the tops of the highest mountains.

IT was the opinion of Boyle that all bodies whatsoever had an atmosphere or a thin fluid substance peculiar to themselves and floating round them; he shewed that the diamond had its atmosphere, the loadstone another. The rose we see has an atmosphere of odorous parts flying round its surface, the musk diffuses perfume in a very wide atmosphere, while assafætida diffuses its scent into a sphere equally extensive. The cælestial bodies almost all of them that we are sufficiently near to examine, have their atmospheres: when a star is sometimes

hid from us behind a planet, we always find as the star emerges from this temporary eclipse, that the planet's atmosphere hides the star for a while longer than we had a right to expect its appearance. As all bodies thus have their atmospheres, so it is but analogous with the usual course of nature, that the earth also should have an atmosphere or a fluid substance floating round it filled with particles; and some have thought that air is nothing more than earth or water expanded, and assuming a more subtil form. These therefore compared the atmosphere to a large chymical furnace; in this the matter of all sublunary bodies is found floating in great quantities. This great recipient, said they, is continually exposed to the action of the sun's heat, from whence results a number of chymical operations, sublimations, separations, compositions, digestions, fermentations, and putrefactions. This sect of philosophers supposed, and brought experiments to prove, that air could be produced from
bodies

bodies at pleasure, that we could make air from earth or plants by a very easy process, and that air was in fact nothing but the parts of bodies, which, by being changed, became capable of different properties.

To this purpose Boyle has related many experiments by which he made air. By making air he meant drawing it in large quantities from several bodies that seemed unpossessed of it before, or at least not possessed of such quantities as were extracted by him from them. He observes, that the best methods for accomplishing this are by leaving the bodies to ferment, to putrify, to dissolve, or in short driving them through any process that will serve to disunite their parts from each other. He adds, that even many minerals, in the parts of which we could expect to meet no such fluid as air, have yet afforded much upon being dissolved in corroding fluids, such as aqua fortis, which separates the parts of the metal from each

other. Hales has made many experiments to the same purpose. However, after all, we are not to suppose the air thus made either from vegetables or minerals is the true elastic air, the properties of which are now under consideration.

ALL that appears air to our senses is not really so, for we can make even water put on for a time the appearance of air, and yet this water, whose nature seems thus in a manner changed, will, when left to itself for a short time, again resume its natural form, and look like water as before.

THIS is proved by the very ingenious experiment of the *Æolipyle*. This instrument is a copper globular body, in which is inserted a small neck or pipe (See Fig. 43.) with a very small orifice, from whence, when filled with water and laid upon the fire, a vapour like wind issues out with prodigious violence, and

and blows like a tempest. The way to fill this instrument with water is to set it first while empty upon the fire till it is hot, and then with a pair of tongs it must be taken off and the pipe held under water till it be filled as much as you think fit. Those who have not this instrument itself, may easily make one something like it with their tea-kettle, only first having filled it with water, and then clapping down the lid very close, stopping it round with loam or any such substance to prevent the steam from escaping any way but by the spout. When this kettle boils, if you hold a candle to the spout you will presently see it blown out with some violence; and if we could bend down the spout in such a manner as to blow against the fire, the kettle would blow the fire under itself like a pair of bellows. If the water put into the kettle instead of being simple were perfumed, this would diffuse the odour with inexpressible strength round the room. If a wind instrument were pro-

perly adapted to this spout, it would make it found. Such are the effects of water when made to resemble air, but still it is altogether different from real air; for when this vapour is caught by a proper receiver, it quickly condenses in drops to the sides of the vessel, and no way differs from common water.

IT is exactly the same with all other counterfeiting fluids and substances as with water; how great so ever the rarefaction, yet they constantly are found after a time to lose the properties of air, and to assume a different appearance. Boyle informs us, that he has drawn an elastic fluid from several bodies, from bread, from grapes, from beer, apples, peas, as also from hartshorn and paper. This substance had, at the first appearance, all the properties of air. But upon examining it more closely, it was so far from being of the same nature with pure air, that the animals which were confined in it, not only lost all power of breathing

breathing in it, but died in it sooner than in a place from whence he had taken out all the air.

FROM this therefore it appears, that there is such a thing as true air, considered as distinct from vapours, from factitious air, or any other minute substance floating in our atmosphere. It appears that it can neither be converted into other substances, nor others converted into it. This real air when shut up in a glass vessel remains there continually without any change, and always under the form of air. But it is not so with vapours, or other rarefied substances; for as soon as they become cold they lose all their elasticity, and adhere to the sides of the glass in the form of round drops, while the vessel which in the beginning seemed filled with the vapour, in a manner becomes quite empty.

ANOTHER property by which this pure air differs from vapours is, that by
these

these we often hinder our breathing, while, without the other, we could not breathe.

It differs also from terrestrial exhalations in this, that it remains the same after great rains and thunder, as it was before them; whereas, if it was only a compound of exhalations, these when fired off in lightning, or falling with rain, would totally destroy the compound, and consequently change the nature of the air; which however is not the case, for the air remains unvaried, or, if it receives any change, they leave it more pure.

WE may therefore rest assured, that there is a substance called air different from all others, and no way allied to them; but then as to the nature of this substance, the parts of which it is composed, the figure of those parts, these are things to which we are utterly strangers; all our opinions upon this head are but
con-

conjecture. Though reason serves to assure us that this pure air must exist, yet we have never had the means of examining it solely and unmixed with other substances. Whatever we breathe, whatever we feel, is but an heterogeneous mixture of different bodies floating in this unknown supporter; and the different noxious or salutary effects ascribed to air belong properly to those foreign mixtures with which it is impregnated.

BOERHAAVE has shewn that the air we breathe is a chaos, or an assemblage of all kinds of bodies whatsoever. Whatever fire can divide floats in the air's bosom, and there is no substance, however hard, that fire is not able at length to separate into fume. Thus, for example, we meet in the air all the substances which belong to the mineral kingdom, as it is called, such as salts, sulphurs, stones, and metals; these all by heat can be dissipated into smoak, and consequently become lighter than the air.

Even

Even gold itself, the heaviest of all minerals, is found in the mine often united with quicksilver; and if we attempt to convert the quicksilver into fumes over the fire, a part of the gold will rise into the air with it.

IN the air floats also all substances that belong to the animal kingdom. The copious emanations that continually fly from the bodies of all animals, by perspiration and other means, (thus if an healthy man's arm be put into a glass case, the perspiration of the limb will be gathered like a dew upon the surface of the glass) these perspirations, I say, send into the air a greater quantity of the animal's substance in the space of a few months than would make the bulk of the animal itself. Even after the animal is dead, if exposed to the air all its fleshy parts will soon be dissipated, and in the warmest climates, this is often found to obtain in three or four days.

THE

THE air is not less loaded with vegetable perspirations. Doctor Hales has calculated that a single sun-flower perspires more than a man, but a full-grown tree perspires in much greater abundance. All these perspirations go to be mixed in the air. When vegetable substances are left to putrefy, they then become perfectly volatile, and make a part of the terrestrial atmosphere.

THUS is our air saturated with an infinite variety of substances foreign to its own nature; but of all the emanations which float in it, Boyle affirms that salts are found in greatest quantity. Some authors think the nitrous salts abound most in air from the frequency of its being found sticking against old lime-walls, and other substances, which seem fitted for drawing it from the air. This has been denied by some of the moderns, who affirm that the nitre is not in the air, but actually in the wall itself. However this be, certain it is that the air is im-

impregnated with salts of some kind or another, and perhaps mixed in a manner perfectly conformable to the chymist's art, for their effects in experiment are as powerful as any salts he can form. Thus the stones of very old buildings are often corroded by the air, and gnawed away in a manner as if it had been done by worms. No unmixed salt in the laboratories of art could do this. From hence we may gather that the bodies which float in air have not only all the properties of which they are possessed singly, but also assume new qualities which they are often found to possess by being mixed together. In the chymist's laboratory new and unexpected appearances continually arise from the mixture of different substances together. In the air, the great elaboratory of nature, more different effects are constantly produced, for the variety of the substances which it mixes together is infinitely more.

THE air then subjected to sense is a very heterogeneous mixture of various exhalations, but what is the base, the fluid that supports these, we are unable to discover. The ancients called it an element, by which they meant one of those substances of which all others are composed. Doctor Hooke calls it Ether, or that subtil matter which is diffused every where. It has received several other appellations, but all this is only calling an unknown thing by different names. The ancients were ignorant of its nature, as well as its properties; the moderns are equally ignorant of its nature, but its properties they have investigated with great success.

C H A P. II.

Of the most obvious Effects of Air upon the Human Body.

E A R L Y Philosophy was content with examining Nature as she offered herself obviously to view. Later enquirers have scrutinized more closely into her secret workings by the means of experiments. Let us first then consider those properties of air which the first philosophers enquired after, and then see what wonders modern experiments have shewn; and thus following nature upon the view, at last pursue her into her more secret recesses.

AIR, as we said already, is the principal instrument of nature in all her productions. If we deprive an animal of air by obstructing the organs by which they inspire it, the animal will die in a few minutes. If we should by any other

means deprive the animal of the free use of air by shutting it into a close vessel, the air with which it is thus included would soon become unfit for all the purposes of life, and the animal would die in a few minutes. Air therefore is necessary for the support of all animals; even fishes that live in water cannot do without it: if a fish is put into a close vessel of water where the external air is excluded, the fish will soon die for want of fresh air. The fishes in a pond covered over with ice would die if care were not taken to break the ice, and so let in fresh air upon the surface of the water to fit it for their respiration.

WHAT may be the uses of the air thus inspired by animals, or why it should be thus necessary for the support of life, is a question philosophers cannot easily resolve. Some are of opinion that there is a salt in the air, which the lungs of animals continually imbibe as they draw in their breath. This opinion they gathered from the fine scarlet colour of

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the blood of the arteries just as it came from being mixed with the air in the lungs, and that dull colour in the venal blood which it had before. The scarlet colour of the blood, they said, resembled what a salt would have given it, while the blackish colour of the blood before it came to the lungs, shewed that it wanted those salts which it afterwards received from the air to fit it for the purpose of animal life. This is not true. There is no more salt in the scarlet arterial blood than in the dusky-coloured venal blood; and in fact, none in either, except a part of that salt we eat.

ANOTHER sect were of opinion that the air was necessary to support animal life, because without it the blood could not be driven through the body. For the air, said they, pressing down upon the large surface of the blood in the lungs, like the piston of a syringe drives it through the tubes appointed for its reception, and so the blood is driven from one tube to another

another through the whole body. This is not true: Because the child in his mother's womb has the blood circulating through his whole body, and no air comes to his lungs whatever.

DOCTOR Whytt has given us some ingenious conjectures upon this subject. He ascribes much to the irritation of the air upon the internal surface of the lungs, which thus contracting to the touch, drives forward the blood through the rest of the body. After all these conjectures, the particular uses of the air in regulating the animal œconomy, are not yet well known, but even children are convinced of its utility. We rather know what harm it would do us if taken away, than the good it does us being given.

THE air produces several effects upon the body in proportion as it is charged with vapours and exhalations. This was well known to Hippocrates, and several succeeding physicians have given us his-

tories of those disorders which are produced by the badness of air. An air charged with the particles either of arsenic or quicksilver will soon become fatal. In the quicksilver mines at Idra I have seen the workmen in general miserably affected from the nature of the atmosphere in which they were obliged to breathe. The most vigorous were in some measure palsied by working there, and that in a few days; scarce any were known to outlive a term of three years constant residence at the mine.

THE air when filled with exhalations from animal bodies acquires a pestilential quality, as it is thought, and these exhalations have been known to corrupt quickly; the common baths of the warm countries, in which several bathe in a morning, if not constantly changed, would soon grow intolerably offensive. It has been theoretically alledged, that if a number of men were crowded into a space of small extent, the exhalations from their bodies would soon form a column

column of seventy-two feet high, which, if not dissipated by the winds, would become instantly fatal to one just placed in it. Theory first asserted this; the number of persons suffocated at Calcutta shews the theory to have too true a foundation. From hence we may infer, that those who build or improve cities, should be very attentive to make the streets sufficiently spacious, and not permit their prisons to be crowded with wretches, whose numbers must necessarily breed infection. It were even to be wished, that people abstained from burying their dead near churches, where there is, or should be the greatest resort of the living. Yet, after all, though air that has been too much inspired by man must be unwholesome, yet probably the air, in some measure, acquires an healthful quality by being moderately peopled, if I may so express it. The air upon a desolate coast, however open and dry the soil, is always found dangerous; while univer-

C 3

fally

fally through Europe the most populous cities are reckoned the most healthful.

IF brass or copper plates be heated in the fire, and the vapour that ascends from them while thus burning be conveyed by blowing or any other means into a close room, animals, in such air, will be instantly destroyed: this is a very convincing proof how much mines of copper may prejudice the atmosphere, and destroy the wholesome qualities of the air.

AIR may be heated by a very easy experiment; a common pair of bellows, having their end or snout heated red hot, will render the air that is blown through it hotter than the hand can bear. Hot air is reckoned extremely prejudicial to health. It has been said, that when air acquired a degree of heat greater than the natural heat of animals, which is usually reckoned to amount to about an hundred degrees by the most common thermometer (as we shall shortly shew) then

it was thought the animal could not live in it. However, this is a mistake; for Mr. Ellis, when in South Carolina, measured the warmth of the air, and found it several degrees greater than animal heat, yet the inhabitants bore its extremity with health and unconcern. However, it will still hold that when the heat of the air is increased to many degrees beyond the warmth of the lungs that breathe in it, it will corrupt the solids and fluids both, and soon bring on death. In a sugar baker's oven, in which the heat was equal to an hundred and forty-six degrees, that is fifty-four beyond animal heat, a sparrow died in two minutes, and a dog in twenty-eight.

COLD in excess has a very injurious effect also upon the health of animals, but its malign influence is neither so sudden nor so sure as that of heat. Cold contracts the animal fibres so much that

the same body measured in hot weather and then in cold, will be found to be shrunk in the latter very considerably. Extreme cold acts on the body like so many small needles entering its surface, at first only producing a slight itching, then a small degree of inflammation, and soon after, if carried to excess, a total stoppage of the circulation. This irritation of cold is felt peculiarly severe upon the surface of the lungs internally, where the thin covering of the parts is easily affected. The cold air entering into the lungs would be actually insupportable, but that a part of the warm air, which was left behind in the former expiration, still remains and mixes with the fresh cold air taken in. However, the continual want of perspiration, the cold closing up the pores of the skin, together with the continual irritation upon the different parts of the body, in a short time produce the most terrible symptoms. The scurvy is the peculiar disorder of cold

countries, a disorder which, in the arctic regions, assumes very different appearances from those which we are accustomed to see in this temperate climate; the joints immoveable, an ulcerated body, the teeth falling, old wounds received in the former part of life breaking open again, these and several such terrible symptoms are the consequence of living in an air too cold for the native of a temperate climate to sustain. Such as desire an history of the fatal symptoms attending this disorder, may consult Ellis's voyage to Hudson's bay, where they will not only see the history of the disease, but also the best methods of preventing it.

AN air too humid produces a relaxation in the fibres of animals and vegetables. The moisture insinuating itself through the pores of the body augments its dimensions. As the string of a fiddle grows thicker and consequently shorter by being moistened, so do the animal fibres relaxed by too much humidity.

A person

A person that swims is more wearied by the relaxation of his fibres by the water, than he is by the fatigue of the exercise itself. This relaxation, if continued to any great degree, soon begets a peculiar train of dangerous disorders; agues, dropfies, and palsies are generally its surest attendants. In short, the air and its peculiar qualities have such an affinity with the human constitution, that it should be our care to study them, if not from reasons of curiosity, at least from motives of self-preservation. As humidity is therefore dangerous to the constitution, there has been a method contrived of measuring the quantity of humidity in the air, that when known we may guard our bodies or chambers against it. This cheap instrument is called the hygrometer or weather-house, which is made merely upon the principle of a piece of cat-gut lengthening in dry weather and contracting in moist weather.

How

How bodies thus with moisture swell and shorten is easily conceived, for the liquid that enlarges the dimension of the fibre one way, will necessarily shorten it the other. If I draw a cat-gut or any other cord to a great length between my fingers, I will make it smaller than it was before; on the contrary, when I let it go and when it thus becomes thicker, it becomes also shorter. To illustrate this a little more, for the question is attended with some difficulty; and the difficulty is, why the same moisture that enlarges the fibres of the cord cross-wise does not also enlarge them length-wise? In other words, why, as the cord swells, does it not also lengthen, for such is the case in timber moistened in water, as Muschenbrook justly observes? This question has been solved by different methods. The following will suffice. If the cord be supposed to resemble an elastic tube or gut, and water be forced into it at one end, the fluid pressing out its sides equally

equally every way, its dimensions cross-wise will be encreased in a much greater proportion than length-wise, and as it is protruded with such excess cross-wise, it must consequently grow shorter length-wise to conform to the forcing power. Such a theory may serve for this wonderful appearance of the cord's shortening by moisture; but timber, the fibres of which are more rigid, will not yield so readily to the influx of the fluid, and consequently will not shorten in proportion as it swells. After all, however, we must leave this subject in obscurity, and what is most extraordinary, naturalists have in general passed it over as an object unworthy their notice. The fact, however, is certain; every day's experience shews us that cords of all kinds contract with humidity, and lengthen when the weather becomes dry. When Trajan's pillar was a second time reared by Pope Sixtus, we are told that the cords of the machine employed in raising it were found too long just when the pillar was

was almost upright. The machinist that directed the whole was at a loss, till a countryman taught him to shorten the cords by the affusion of water. However true this story may be, the hygrometer when its cord is shortened will mark the humidity of the air, and when the same is lengthened it will denote its dryness. The usual method of making an hygrometer is as follows. Let A B C (See Fig. 44.) be the lower part of a twisted line or cord hanging from the height of the room against the wall or wainscot. On the wall let there be described a large circle graduated into an hundred equal parts, such as K L M N; in the centre of this circle is fixed a pulley turning upon its axis, and bearing an index or hand upon it O P. If now a cord be put round the pulley, and a small weight or ball suspended at the lower end to keep the cord tight, as the cord gathers moisture from the air it will become shorter, and consequently turn the pulley upward, and the index rising with

with it will point higher as the air is more moist. This is an hygrometer that any person may make; but an easier and still a cheaper I am told may be made by a wild oat-beard, which lengthens with dry weather and contracts with moisture much more sensibly than any other substance whatsoever. A very small share of ingenuity may form it into a graduated hygrometer, and the simpler it is constructed the better.

C H A P. III.

*Of the most obvious Effects of Air upon
mineral and vegetable Substances.*

THE effects of the air, by which I at present mean that heterogeneous mixture that floats on our atmosphere, are still as apparent in the alterations produced on some minerals and vegetables as on man. In fact, it is most likely that all natural corruptions and alterations proceed from the air alone; for if we keep the air from either minerals or vegetables by any contrivance, either by oiling the surfaces of the one, or stopping up the others pores close; in such cases neither will metals rust, nor vegetables putrefy. If the air is kept from them, they are seen neither to encrease or diminish, metals cease to change, and vegetables to grow or to corrupt.

THOSE metals which the air can penetrate, such as iron, lead or copper, are soon touched,

touched, rusted, and in a number of years are corroded entirely away. On the tops of high mountains, where the air is not so much impregnated with foreign materials, things are not so apt to change. Words written upon the sand or the earth in these places have been legible forty years after, and appeared no way disfigured or defaced.

BUT though the air, which is a subtil fluid, penetrates iron or copper after a series of years, yet in immediate use the pores of either give it no admission. The air will pass through the pores of lead unless the metal is first hammered upon an anvil. It will not pass through hard stone, nor wax, nor pitch, nor rosin, nor tallow, these substances effectually resist its admission; and if vessels should be made of these substances, or lined with them, they would keep the inclosed air which was blown or driven into them for some years without losing any part of it. After a long series of years,

years, however, the air will eat its way through these substances, and thus contrive its own escape.

THESE keep the air for a long time. There are other substances which the air will soon penetrate. It will insinuate itself through wood, however hard or close it may appear. It will pass through dry parchment, through dry leather, paper, or a bladder turned inside out; but if these substances be moistened either with water or oil, they then become airtight: However, if the air be very much rarified, it will not pass through all sorts of timber; and if the timber be oiled, it will resist the air better than before. There are but two substances that resist the air, and confine it without being corroded by it; namely, gold, and vitreous or glassy bodies, such as gems of all kinds, and common glass.

LET us now therefore see what are the effects of air when it thus insinuates itself

into the pores of bodies and mixes itself with them. We have already said that the air contained a mixture of different substances, salts, metals, sulphurs, and such-like; these when uniting with the surfaces of terrestrial bodies must naturally corrode them, as we see aqua fortis, which is made of a mineral acid, corrode iron. It is not less corroded in the space of a few years by the acid of the air; and the most usual methods of preventing this acid salt from entering its surface, is either to close up the pores of the surface by giving the iron the highest polish it is capable of bearing, or by oiling it, which will answer till the oil is evaporated. Boerhaave assures us, that he has seen iron bars so much corroded by the acid of the air, that he could crumble them between his fingers like dust. As for copper it is soon corroded by the air, and covered with a green rust like verdigrease, which is no other than the acid of the air mixed with the parts of the metal. As for lead, tin, and silver,

silver, they all contract a rust in like manner. Acoſta informs us, that in Peru the air diſſolves lead entirely; and we ſee our leaden pipes affixed to houſes that have been a long time expoſed, very much injured by the corroſion of the air. Gold is the only metal which we find the air will not ruſt or conſume. The only ſubſtance that conſumes gold is ſea ſalt; this ſalt it is almoſt impoſſible to raiſe into the air, or volatilize, as it is called. It is not wonderful therefore that the air cannot conſume or ruſt gold, ſince it wants the ſalt adapted for this operation; all other ſalts are more eaſily volatilized and made to ſwim in the air, and therefore every other metal finds in the air the ſalt adapted to corrode it. In elaboratories, however, where aqua regia is made, ſea ſalt is volatilized in ſome quantity, and in theſe places gold is actually found to ruſt.

IN the operations of the chymiſt many of the changes of bodies are very different, if they be made in a cloſe or an

open air. Thus camphire burnt in a close vessel dissolves all into salts; when, on the contrary, if the same process were carried on in the open air, the whole would dissipate into smoke. In the same manner, if sulphur be placed upon an iron plate under a glass bell, with the edges close stopped, fire being placed beneath, the sulphur will rise in spirits round the internal surface of the bell; but if by the smallest opening the air within the bell has a communication with the external air, the sulphur will instantly take fire, and the whole will be consumed. An ounce of charcoal inclosed in a crucible well stopped will remain in the fire a whole fortnight without being consumed or losing any of its weight; whereas the thousandth part of the same fire applied to it in open air would have consumed it entirely. Van Helmont adds, that during the whole time the charcoal does not even lose its blackness, but upon the air's being introduced but for a moment, the whole
mass,

mass, tho' black before, falls into white ashes. What befalls the charcoal in this experiment, will likewise be the case with all other vegetable or animal substances that are burnt in the fire in a close vessel and then immediately exposed to the air.

THE air, when impregnated with the vapours of a mineral, destroys all substances that such a mineral would destroy. Thus, in a place where a mineral ore is found in great abundance, the air is impregnated with a vitriolic acid that corrodes whatever it touches. In London, where there is much coal burnt, and where the air is consequently impregnated with sulphur, experiments upon salts are very different from what they are in an air of a different kind less sulphureous. For this reason, the metal utensils are found not to rust so soon in London as in some other parts of the kingdom where wood or turf is the only fire used in common. For in these latter places the air abounds with corroding

salts, which, in London, are overcome by the fumes of the sulphur; and this may be one reason among others why that great metropolis is so healthy.

THE influence of the air upon some saline substances is still more apparent than what we have yet mentioned. Many of them, which, when the air is kept away, continue for a long time under the appearance of crystals, upon its admission extract all its humidity, and melt without any other liquid added to them. Some upon the admission of the air change their nature, and from what chymists call fixed salts become volatile, as, for instance, salt of tartar, when exposed to an acid air. On the contrary, volatile salts become sometimes fixed.

IN India, where the nitrous salts are found by experience to abound greatly in the air, they dye many colours in much greater perfection than we can in England. In Guinea, the heat, joined with the humidity, cause such putrefaction

faction in every vegetable and animal substance, that the best drugs lose their virtues in that terrible climate. In the island of St. Jago belonging to Spain, they are obliged to expose their bales by day in the sun to dry them from the moisture they have contracted during the night.

WHEN the Dutch, saith Boyle, cut down the clove trees of the island of Ternati, of which it was full, in order to inhance the price of cloves in Europe, this produced such a change in the air, that the island from being extremely healthy, became sickly and unhealthful to an extreme degree. A physician who was then upon the spot, assured Mr. Boyle that these disorders proceeded from the noxious vapours of a volcano that was upon the island, and against which, in all probability, the vapours perspired by the clove tree were an effectual antidote.

THESE and numberless similar instances might be produced of the power

of the atmosphere over terrestrial bodies. Whatever chymical dissolvents can perform, the atmosphere will be found in time to do the same. For the terrestrial body will attract from the air those substances with which it has the greatest affinity; and as straws are attracted by amber, so will the acid and vapours of the air by substances on earth peculiarly adapted to receive them; so that the doctrine of attraction is bound to explain all the chymical changes in nature. The very seasons are under its influence; whatever alters the heat of the atmosphere, as we observed above, alters also the nature of the air. By this heating property, Boyle supposes that salts and other substances are kept liquefied in air, and that being melted together they act conjunctly. He supposes, that by cold they lose their fluidity and their motion, that they crystallize and separate one from the other, and by their weight hang close to the surface of the earth, cling to all substances, and prevent vegetation.

C H A P. IV.

Of Air considered as a Fluid.

SUCH are the most obvious of that heterogeneous assemblage of bodies in our atmosphere; but that fine and perfectly transparent substance the true natural air which supports them, comes next to be taken into consideration; and its fluidity, or the easy yielding of its parts, is one of the most obvious of its properties. The ease with which it gives way to the swiftest bodies need scarce be mentioned; sounds travel through it with great rapidity, odours and emanations of all kinds find no difficulty in moving forward and pressing aside its parts to make way for their own. These all demonstrate the air to be a most yielding substance which gives way, if not prevented, to every impression; and this is but another name for fluidity. This
fluid

fluid quality the air never loses, though it be kept never so long in the closest vessels, though it be exposed to the greatest vicissitudes of heat or cold, or though it be prest together with the utmost violence of human force assisted by machinery. Still the air continues that yielding fluid it was at first; in all these cases it was never found that any of its parts became solid, and unbending to the touch, or that they were reduced into any other substance different from air. Why the parts of this fluid still retain their usual form we cannot tell; to understand this would require a knowledge of the figure of the small parts of air themselves; to understand this, it would be necessary to know the dimensions of those small parts, and also to know their mutual tendency to attract or repel each other. None of these however are known to us, and therefore the cause of the air's fluidity must still remain a secret; it is sufficient that we know that it is a fluid, the appearance and not the cause is all that

that we are permitted to understand. Cartesius ascribes its fluidity to an intestine motion in its parts. But whence arises the intestine motion? This motion is even more difficult to be accounted for than fluidity itself, a greater wonder is therefore supposed in order to account for a less. Boerhaave ascribes the fluidity of the air to the heat of the sun, which keeps it in a state of liquefaction; and he supposes the whole atmosphere would congeal into one solid mass if it were not for the assistance of the sun's fire. This is contrary to experience; no degree of cold can in the least alter the air's fluidity, or unite its parts into the form of the smallest solid: Besides, on the tops of the highest mountains where the cold is greatest, the air is (to use his own expression) most liquefied. Newton's followers have attempted to explain the fluidity of the air by means of their great instrument attraction. The parts which constitute the mass of the air, say they, may be supposed to be globular, they

they therefore touch each other in very small surfaces, as all globes must. The attraction between two bodies that touch will be less in proportion as the surfaces that touch, and the quantities of matter in the touching bodies are little. In the parts of air therefore, as both are extremely small, the attraction must be also very little, and the parts will consequently be separated from each other with the greatest ease. This hypothesis, however, supposes, what, if denied, can never be proved; namely, that the parts of the air are globular; we do not know of what figure the parts of the air consist. However, though we do not certainly know the figure of the parts of the air, it is very possible they are spherical or globular; first, because bodies that are of that figure roll over each other, and give the easiest way to any impression made upon them; and secondly, because the larger parts of such fluids as we can view with a microscope, are of a spherical figure. Thus the parts of mercury
rising

rising in fume are all spherical, the parts of the blood running through a very small transparent vein are spherical, so is the chyle or that part of our nutriment which is going to be turned into blood. Derham having examined with a microscope a ray of light passing from the sun into a dark room, found that all the vapours which danced to and fro in this ray were perfectly globular. If therefore all the grosser fluids are composed of spherical parts, we may from analogy conclude that more subtil fluids are composed of the same. But notwithstanding this similitude, we must consider the air as a very different kind of fluid from water, oils, mercury, or such substances which are called peculiarly liquids. All the parts of liquids we find, when in any quantity, sunk with a level surface; but the air, for aught we know, assumes no such surface.

BUT though the air differs from other fluids in several properties, which we shall

shall shortly see, yet it agrees with all fluids in this, that it presses in all kinds of directions with equal force; that is, suppose I should confine air in a bladder, it presses against all parts of the sides of the bladder with equal force, and if the air be continued to be driven in, it will burst that part of the bladder which is weakest. That the air presses with as much force any one way as another, that it presses upward, downward, sideways, obliquely, in all directions with equal force, may be concluded from an experiment of Mr. Mariotte. He took a long bottle with a small hole towards the middle of its side. This bottle being filled with water, the hole being in the mean time closed with the finger, a glass tube open at both ends was dipped into its mouth, so that the lower end of the tube came below the little hole on the side. The mouth of the bottle was then well closed round the tube with wax, so that no air could enter that way. This being done, water was poured into the tube to
fill

fill it, and the finger was taken from the hole on the side. If with a finger in the mean time the top of the tube were stopped, and the side hole thus left open, no water would pour through the side hole at all for want of vent at top, as the vulgar expresses it. But both holes being left open at top and side, the effects that followed were these. The water ran out of the side, and descended in the tube to below the level of the hole, and the rest of the bottle remained full. Now from this it appears, that the perpendicular pressure of the air through the tube is but just equal to the lateral pressure through the hole. For if it exceeded, then the whole of the water would be driven through the hole on the side, which however is by no means the case, for the air upon the side hole presses as forcibly as that which comes down the perpendicular opening of the tube, and therefore the air presses equally in all directions.

FROM

FROM this experiment therefore it appears, that air presses in all directions, upwards, downwards, laterally, and obliquely. Now, why should we not consider the particles of air as thus pressing in all directions upon each other, and if they press each other equally every way, their figures must most probably be spherical. This however is only offered as a conjecture, and luckily for mankind, it matters not whether these conjectures be true or false.

C H A P. V.

Of the Weight of the Air.

AS light as air, is an expression made use of in common conversation, yet it is much heavier than is commonly imagined. We have numberless proofs of its weight, many of which though the ancients could estimate as well as we, yet they considered it as a substance totally void of gravity, and called it an element. An element was something different from earthly matter, and therefore they considered it as wanting material ponderosity. The usage of an undefined name thus satisfied all their curiosity. However all material substances, of which air is one, have weight; like other bodies it falls to the earth, and is more dense as it approaches its center. All people know that air on the tops of high mountains is much rarer and thinner than it is below in the valley; if they should doubt it, the dif-

ference they will find in drawing their breath in the different places will clearly convince them. As they go up a very high mountain their breathing becomes quicker, the atmosphere becomes clearer, neither clouds nor vapours are able to rise to such heights, and therefore as he ascends the traveller leaves the tempest and the storm midway below him. Ulloa, who went to take the measure of a degree upon the Andes in Peru, which are the highest mountains in the world, tells us, that when clouds gathered below the mountain's brow while he stood on the top, they seemed like a tempestuous ocean all dashing and foaming below him, here and there lightnings breaking through the waves, and sometimes two or three suns reflected from its bosom. In the mean time he enjoyed a cloudless and serene sky, and left the war of the elements to the unphilosophical mortals on the plain below him.

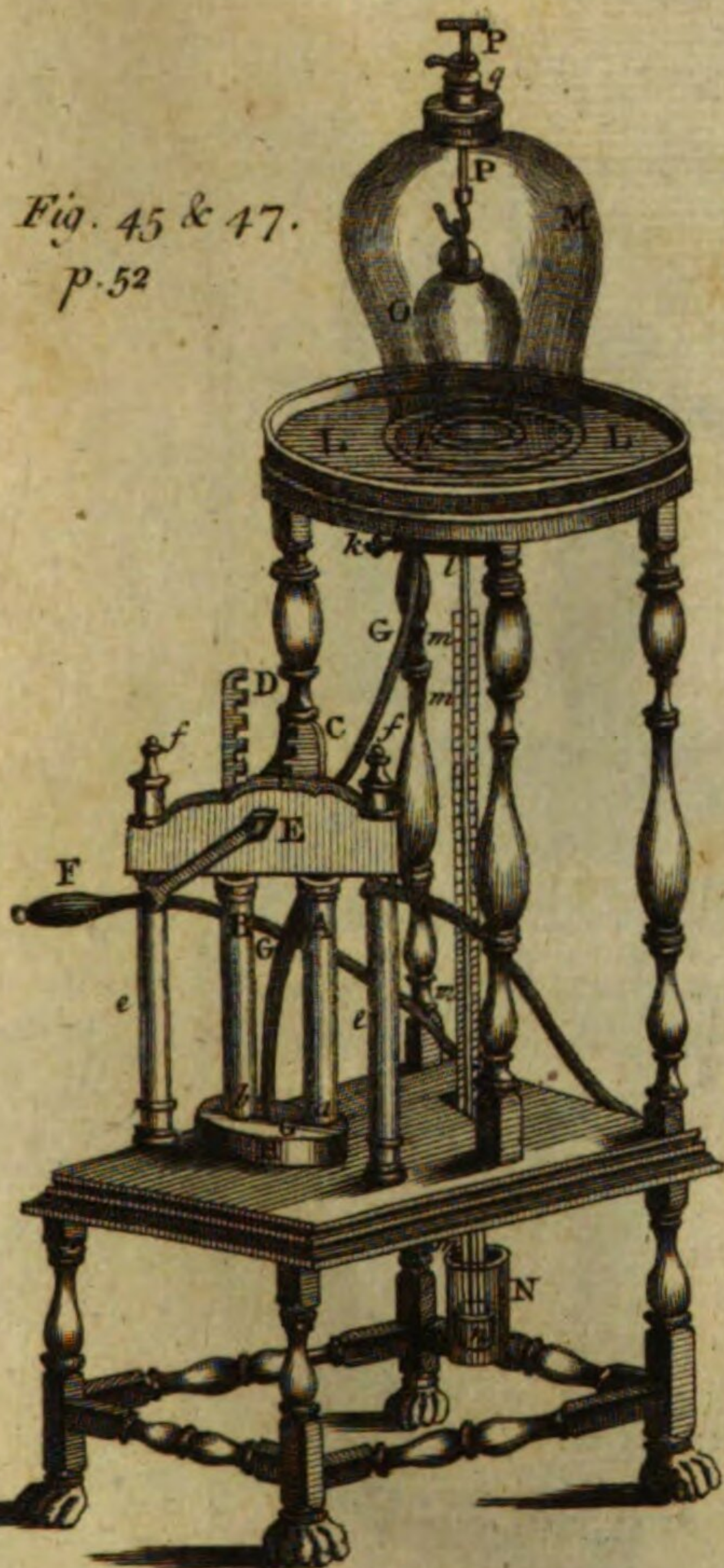
SUCH appearances as these, with which the ancients were as well acquainted as we,

we, might have led them to consider the air as having weight; but they were not at this time acquainted with a machine which serves to discover its weight by proofs much better calculated for conviction than those brought from untried nature. The machine I mean by which we so plainly discover the weight of the air, is the air-pump. For the first invention of this, the world is indebted to Otho Gueric, a German; but it was our countryman Boyle who turned it to real uses, it was he who improved it, and applied it to philosophical purposes. In the hands of Gueric it was a mechanical instrument; in those of Boyle it was a truly philosophical machine. By this machine we can with ease empty a glass vessel of its air, and put what bodies into it we think fit. Thus comparing the changes wrought upon bodies by being kept from air, with the same bodies when exposed to air, we come to a knowledge of the effects of air upon bodies in general.

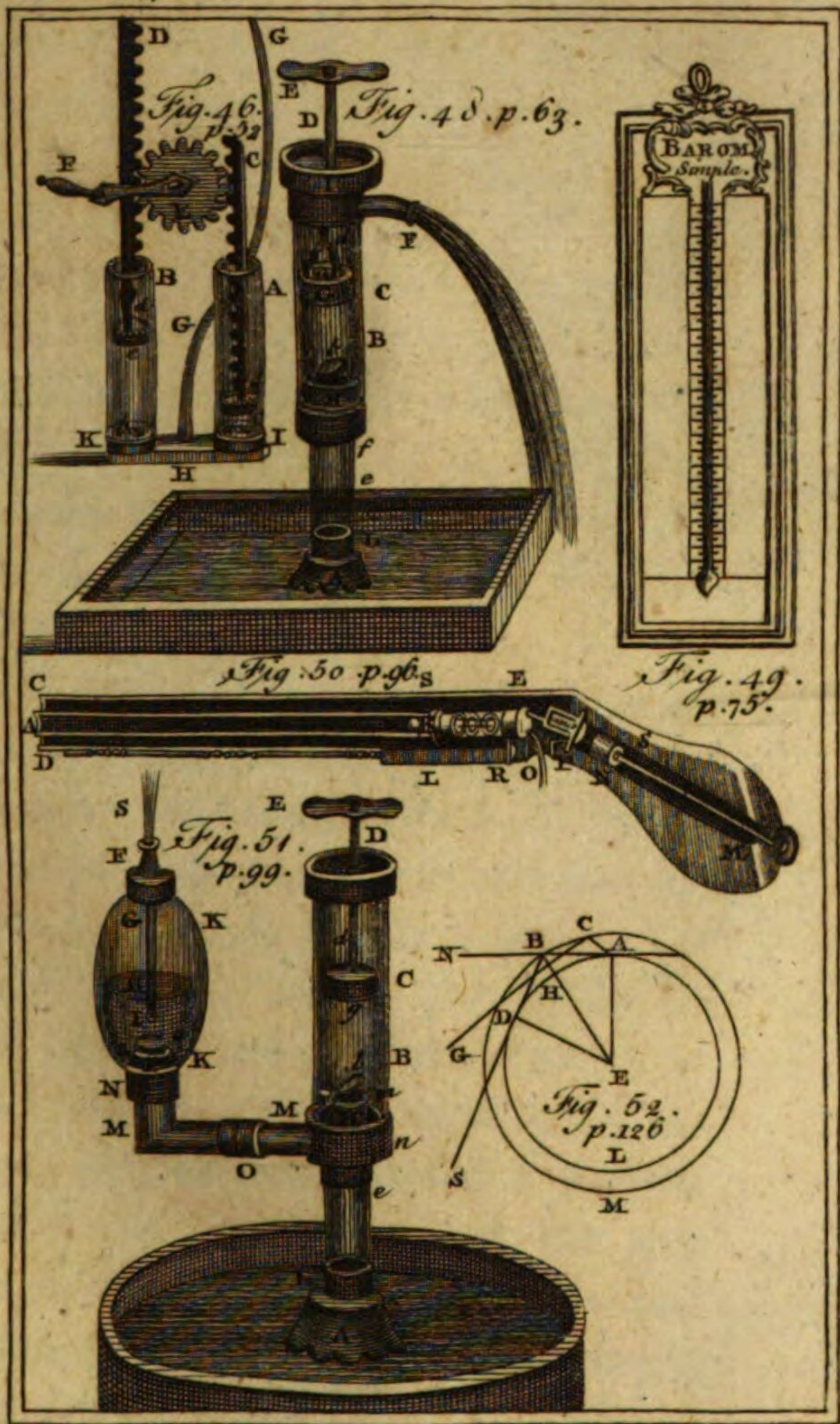
BUT before we come to examine the uses of this machine, let us first give its description as it is in its present state of improvement: rather describing the instrument as already made, than giving directions how to make it.

HAVING put a wet leather on the plate L L, (See Fig. 45.) place the large glass or vessel receiver M with its mouth downwards upon the leather, so that the hole *i* in the plate may be within the glass. Then turning the handle F backward and forward, the air will be pumped out of the receiver by the contrivance of the mechanism below, which we are going to describe. As the handle F, represented more at large (Fig. 46.) is turned backwards, it raises the sucker or piston *d e* in the hollow barrel B K by means of the toothed wheel F engraining in the toothed rack D *d*: and as the piston or sucker is leathered so tight as to fit the barrel exactly, no air can get between this piston and the barrel, and therefore all the air above *d* in the barrel is lifted
up

Fig. 45 & 47.
p. 52



Proud sc.



Proud sulp.

up towards B, and a vacuum made in the barrel from *e* to *b*: upon which part of the air in the glass M (Fig. 47.) by its spring rushes through the hole *i* in the brass plate LL along the pipe G G, which communicates with both barrels by the hollow trunk I H K, and pushing up the valve *b* (a valve is a bit of leather that covers a hole as the flapper of a bellows, admitting the air in, but suffering none to go back) pushing up the valve, I say, the air enters into the vacuity *b e* of the barrel B K. For the air will naturally press into those places where it is least resisted.—All this is done by drawing the handle towards D. Now then turning the handle forward the contrary way towards C, the piston *d e* is depressed in the barrel, and as the air which had got into the barrel cannot be pushed back through the valve *b*, for the valve closes like the flapper of a bellows, and will not let the air back the way it came, the air must therefore ascend through an hole in the piston, and escapes

through a valve at *d*; and is hindered by that valve from returning into the barrel when the piston is again raised. At the next raising of the piston, a vacuum is again made in the same manner as before, between *b* and *e*, upon which more of the air which was left in the glass receiver *M* gets out thence, and runs into the more empty barrel *B K* through the valve *b*. The same thing is effected with regard to the other barrel *A I*, and as the handle *F* is turned backwards and forwards, it alternately raises and depresses the pistons in their barrels, always raising one while it depresses the other. And as there is a vacuum made in each barrel when its piston is raised, every particle of air in the receiver *M* pushes out another through the hole *i* and pipe *G G* into the barrels, until at last the air in the glass receiver comes to be so much rarefied that it can no longer get through the valves, and then no more can be taken out of the receiver. From which it appears there is no such thing as
making

making a perfect vacuum in the receiver ; for the air that leaves the receiver is driven out by that which remains behind, there must therefore some remain behind at last.

THIS is the construction and nature of the celebrated air-pump. Some instruments at first contrived only for explaining science, become at last by frequent use a part of the science itself, and demand an equal explanation. Such is the case with this ; and the reader must pardon our prolixity in the description. There is a cock *k* below the plate *L L*, which being turned, lets air into the receiver again. There is a glass tube *l m n* open at both ends, and about thirty-four inches long, the upper end communicating with the hole in the pump plate, and the lower end immersed in quicksilver at *n* in the vessel *N*. To this tube is fitted a wooden ruler *m m*, divided into inches and parts of an inch from the bottom at *n*, where it is upon a level

with the surface of the quicksilver, and continued up to the top, a little below *h*, to thirty or thirty-one inches. Now the quicksilver in this tube rises as the air is exhausted in the receiver, for it opens into the receiver through the plate *L L*. And the more the air is exhausted, the more will the quicksilver rise, (for a reason we shall shortly see) so that by this means the quantity of air pumped out of the receiver may be very exactly measured.

By means of this instrument the first thing we learn is, that the air is actually heavy. If a vessel be by means of the air-pump exhausted of its air, if we clap the palm of our hand to its mouth we shall quickly perceive the weight of the air upon the back of the hand, pressing the hand in a manner into the vessel. If a part of the skin of a bladder should be placed there instead of the hand, the external air would break the skin with great force, and rush into the vessel with
a noise.

a noise. If the air be pumped out of a square glass vessel, the weight of the external air will break the glass in pieces. If a flat piece of glass be fixed upon the top of an exhausted receiver, the air without, pressing upon the flat glass, will break it all to pieces. But to put the air's weight past all doubt, we can actually weigh it in a balance, and it is there found heavy.

HAVING exhausted the air out of a thin glass flask, and suspended it at one end of a balance, which being nicely counterpoized by weights in the other scale. This done, admit the air into the flask, into which it will rush with a noise, and though the flask was balanced before, it will now upon the admission of the air become heavier and preponderate. If the flask holds a quart, it will be found that the weight of the air it now contains is about seventeen grains above what it was when quite empty, so that a quart of air weighed upon an
average

average in the open air, is about seventeen grains.

Now, if a single quart of air weighs so much, what would not a pillar of air weigh, the base of which rests upon earth, and whose top reaches several miles above the clouds. The weight of this pillar must surely be great! The weight of such a pillar, how extraordinary soever it may seem, can be determined with the nicest precision. We mentioned just now with what extreme weight such a pillar rested upon the back of the hand which had no air under it to keep it up, or balance the weight above it of the air, but we cannot precisely tell how great that force is as yet. Let us go a little farther then, and see with what weight this high pillar of air would press upon the surface of a tub of quicksilver. Let us suppose a long glass tube exhausted of all air, and stopped close at the top, to be plunged at the other end into it. It is evident that the air will
press

press upon the surface of the quicksilver without; and if there were air in the tube, it would press up the surface of the quicksilver within the tube also: but there is no air at all, as was said, within the tube, for that was exhausted before the experiment; so that in short all the air will press upon the quicksilver on the outside of the tube, and none upon that within. The air, therefore, as it has great weight, will press the external surface of the quicksilver all over, and drive it up into the hollow of the tube, where there is no pressure from air at all. As if I pressed down the palm of my hand upon water, the water would rise up between the interstices of my fingers where the pressure was least: By means of this pressure of the heavy air upon the quicksilver, the quicksilver will be driven up into the tube, and rise in it, if the tube be long enough, about twenty-nine inches and an half high.

THUS

THUS then the air presses down with a weight capable of making quicksilver rise to twenty-nine inches and a half. A pillar of air therefore that reaches to the air's greatest height, is just as heavy as a pillar of quicksilver of the same diameter that measures exactly twenty-nine inches and an half. For the weight of the air pressing down must be just exactly equal to the weight of the quicksilver that is pressed up. When one body raises another to its highest pitch, and can raise it no more, the body raised then equals the body raising. We may therefore boldly conclude, that a pillar of air which reaches from the top of the atmosphere, weighs just as much as a pillar of quicksilver twenty-nine inches and an half high. The weight of such a pillar we can easily estimate, and consequently measure the weight of the atmosphere; but first let us mention another case similar to this of the quicksilver, which is, water.

IF by any means we exhaust all the air from a vessel more than thirty-two feet high, and stopping one end, set the other in water, the water will rise thirty-two feet within the vessel and no higher, for the weight of the air will press upon the surface of the external water as it did before upon the surface of the quicksilver, and press up the one as well as the other with all its weight. A pillar of water of thirty-two feet high just weighs equally with a pillar of quicksilver twenty-nine inches; the air therefore presses up that thirty-two feet, as it pressed up this twenty-nine inches. The weight therefore of a pillar of the atmosphere is equal to either a pillar of quicksilver twenty-nine inches high, or to a pillar of water thirty-two feet high; it is equal to either, for they are equal to each other.

I shall mention an obvious experiment to this purpose, which the student can put into practice without any apparatus while

while at tea. Some water being poured into a faucer, let him burn a bit of paper in a tea-cup, which will drive the air out, and make a vacuum in the cup. Then while the paper is yet burning, let him turn it down paper and all into the faucer, and the air without will press the water up from the faucer into the cup. The water will stand within the cup in a column, and if the cup were thirty-two feet high, and the air within it perfectly exhausted, the water would rise so high in it; as we have said before.

IF what has been said is well understood, the student will be at no loss to account for the rising of water in pumps, or the standing of the quicksilver in the barometer.

A PUMP is a machine of so much utility, that its construction must be described before we proceed. It is used as we all know for raising water from deep wells, and thus saving the labour
of

of winding it up with buckets, or going down into the well ourselves to raise it. The whole machine is formed upon this principle, that the air will press up a column of water thirty-two feet high into a tube or pipe in which there is no air. The air is drawn out of the tube by a piston or sucker, and the water follows it. The tube A B I (See Fig. 48.) which we will suppose is made of glass, represents the pump, or pump-stick, as it is vulgarly called. In this there is a piston D d G, which we can push up and down like the handle of a syringe, or a churn. This piston is leathered round at G so as to fit the bore exactly, without suffering any air to come between it and the tube or pump-stick. Now then hold the machine thus constructed upright in the vessel of water K, the water being deep enough to rise at least as high as from A to L. The valve *a* is fixed within the moveable piston G, and the valve *b* on the fixed box H, which quite fills the bore of the pipe or barrel at H.

These

These valves are so made as to let all the water come upward, but to suffer none of it to pass downward, for the more the water presses back, the closer they shut. Now then the work begins: by the handle E the piston which was first at B is drawn up to C, and this will make room for the air in the pump below the piston to dilate itself, and therefore it will have less weight than the air on the outside of the pump barrel, and the outside air will therefore press up the water into the tube in proportion to the excess of its weight. Therefore at the first lift of the piston the outward air will press up the water through the notched foot A, into the lower pipe about as far as *e*. This will contract the rarefied air in the pipe between *e* and C into a smaller compass, and thus it will become as heavy as it was in the beginning. As its weight or rather spring therefore becomes as great as that of the outward air, the outward air can press the water at this time no higher than *e*, and the
valve

valve *b*, which was raised a little by the air's rising through it, will again fall back and stop the hole in the box H, the surface of the water standing at *e*. Then the piston is depressed from C to B, and as the air in the part B cannot get back again through the valve *b*, it will, as the piston descends, raise the valve *a*, and so make its way through the upper part of the barrel *d* into the open air. But upon raising the piston G a second time, the air between it and the water, in the lower pipe at *e*, will be again left at liberty to fill a larger space, and so its weight being thus diminished again, the pressure of the outward air on the water in the vessel K will force more water up into the lower pipe from *e* to *f*, and when the piston is at its greatest height C, the lower valve *b* will fall back, and stop the hole in the box H, as before. At the third lifting up of the piston, the water will rise through the box H towards B, and then the valve *b*, which was raised by it, will fall back when

the piston *G* is at its greatest height. Upon depressing the piston the third time, the water cannot be pushed back through the valve *b*, which keeps close upon the hole whilst the piston descends. Upon raising the piston the fourth time, the outward pressure of the air will force the water up through *H*, where it will raise the valve, and follow the piston to *C*. Upon the next depression of the piston, it will force down into the water in the barrel *B*, and as the water cannot be driven back through the valve *b* now close, it will raise the valve *a* in the piston as this is driven down, and it will also be lifted up with the piston when that is raised next; for the valve *a* will not permit it to go back again. And now the whole space below the piston being full of water, as it is alternately raised and depressed, the water will rise through its valve, but cannot descend by it; for it closes the firmer the more the water pushes back. Therefore, as the piston continues to work, fresh water will continually

tinually get up through it, and none getting down, it must necessarily run out at top through the pipe F. And thus, by continuing to raise and depress the piston, more water still will be raised, which getting over the pipe F into the wide top I, will supply the pipe, and make it run with an uninterrupted stream. So then at every time the piston is raised, the valve *b* rises, and the valve *a* falls; and at every time the piston is depressed, the valve *b* falls, and the valve *a* rises. By this contrivance it is, that water is raised in our usual pumps (for there are other kinds of pumps which we shall examine at another time) and if the exhausted tube in which it rises be thirty-two feet high, the water will ascend to that height, and no higher; for the air on the outward surface of the water can press it down only with a weight equal to a pillar of water thirty-two feet high.

WHAT we have now seen with regard to pumps, we may every day see

practised in a smaller degree by the common syringe. If one of its ends be put into water, and the piston be drawn up, this will make a space void of air, and the water will be pressed up into the void, and thus fill the syringe.

WHEN children suck at the breast, it is by a natural mechanism somewhat resembling that of the syringe; for the child swallows the air in his mouth, then stops its entrance into the mouth by the nostrils, and then squeezes the nipple between his lips, so that no air can come that way. Thus there is a void in the mouth, and the external air pressing upon the mother's breast, squeezes the milk into the infant's mouth, and by this means it finds the nourishment proper for its support.

CUPPING-GLASSES may be explained upon the same principle. That part of the body under the mouth of the glass has no pressure of air upon it; for the
air

air was driven out of the glass by heat, before the glass was applied. The humours of the body are pushed to that place where they find least resistance.

ALL these appearances in nature are performed, as was said, by the weight of the air pressing the fluids into places where there was no air, nor any other resistance. But though these truths are now as obvious as they are astonishing, yet for many ages the causes of the ascending of water in pumps was utterly unknown. Philosophers were content with thinking after Aristotle, and his opinion was, that nature hated a void or empty space, and therefore made all possible efforts to fill it when the art of man had made one. All this may be very true; but we want to know, why nature hates this void? And here their philosophy was puzzled. Torricelli was the first who undertook to explain, as we have seen, why nature made haste to fill up this void. An accidental

experiment put him into the right road towards the discovery. Having filled a tube, which was stoppt at one end, with quicksilver, and then fixed this tube with its open end in a tub filled with the same: the quicksilver in the tube did not all descend into the tub, but stood in the tube at the height of twenty-nine inches and an half. This experiment was soon communicated to the learned of Europe: the genius of the times all over Europe was then employed in quest of new adventures; Boyle, Paschal, and Riccioli, set themselves to consider this new phenomenon; and this led them to the following conclusions. Water rises in a void thirty-two feet high, as we have for ages seen in pumps; quicksilver stands twenty-nine inches high, as we see in this new experiment; a pillar of the one weighs exactly as much as a pillar of the other; the ascent of both therefore must be ascribed to one and the same cause. And why may not this cause be owing to the pressure of a pillar of air?

And

And if the pressure of this pillar of air were taken away, would the quicksilver then stand in the tube? Let the Torricellian tube, vessel, quicksilver, and all, be placed under the glass of the air pump, and let the weight of the air be taken away from the quicksilver. It will then be found to stand no longer suspended in the tube, but will sink down to the same level with the rest of the quicksilver in the vessel in which it is placed. This was enough, and indeed fully sufficient to convince them, they pursued the track of light as it led, and at length they deduced a theory of the air equally clear and convincing.

WE mortals, who are upon the surface of the earth, said they, resemble fishes at the bottom of the ocean: like them we are enveloped in a fluid of air, which rises far above our heads, an ocean of atmosphere, which while on earth we cannot quit. This atmosphere furrounds our whole earth for some miles high, enveloping the

earth on every side. Let us suppose the tops of the highest mountains thrusting up their heads through this great fluid, like rocks in the ocean that almost rise to, but not quite so high as the surface. As the parts of this ambient atmosphere are all heavy, they press down one upon another, and those parts that are lowest will suffer the greatest pressure, as they have the greatest number of parts above pressing them down. The lower vallies will, therefore, suffer greater pressure from the atmosphere than the higher mountains. Let then the Torricellian tube be brought into a low valley: here the pressure upon the quicksilver will be greatest, and it will rise above twenty-nine inches and an half. Let it be now brought up to the top of an high mountain: here the pressure will be least, and it will sink down proportionably. On the summit of Snowdon-hill, Dr. Halley found the barometer above three degrees lower than at the bottom. On the summit of an Alpine

pine mountain, the Abbè Nollet found it a quarter less high than on the plains of Piedmont. Thus therefore the tube of Torricelli, by the quicksilver rising or falling, will serve very exactly to measure the weight of the air.

As the quicksilver in the tube sometimes in the same place stands an inch or two higher, and sometimes several inches lower, than twenty-nine inches and an half, it is very plain, that the air is sometimes heavier and sometimes lighter: that when heavier, it presses up the quicksilver above twenty-nine inches; when lighter, the quicksilver suffering less pressure rises not so high.

THE tube therefore will exactly determine these variations, and its heights will alter with every change. This instrument was first called the Torricellian Tube; but being now made use of for measuring the alterations and weight of the air, it is called the Barometer, or
Weather-

Weather-glass. The simplest and perhaps the best method of making the barometer is thus: a glass tube, of about thirty-five inches, hermetically sealed at one end, is to be filled with quicksilver. Hermetically sealing a glass is no more than holding the end in the flame of a candle, or fire, until the glass softens, and then twisting it round, so as quite to close up the orifice, and filled with quicksilver well purged of its air, which it may be by boiling the quicksilver in water. The finger being then placed on the open end, this end is set into a basin of the same prepared mercury. Then upon removing the finger, the mercury in the basin will join with that in the tube, and that in the tube will sink down to about twenty-nine inches and an half, one time with another. Instead of a basin at the bottom, the lower end is usually turned up, and dilated into a sort of cup, containing a quantity of quicksilver; upon which the air presses, and so drives it up along the
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the bend of the tube to the usual height. This tube thus fitted and filled is then fastened to a board, which has the inches marked upon it; and towards the top those inches are divided into their parts, in order to measure the rising and falling of the quicksilver more precisely. (Nollet, fig. 25, vol. II. plate 5.)

IT is no easy matter to make a barometer which shall vary with the minutest variations of the weather, for there are several requisites which must be attended to for this purpose. The tube must, in the first place, be of an equal bore from top to bottom, which few glass tubes are found to be. The mercury must be perfectly free from air, which it seldom is. The tube must be no wider in warm weather than in cold, which is impossible. These and some other inconveniencies have induced artists to try other methods of making barometers: they have employed different fluids, such as spirit of wine, water, oil,

oil, and such like : the simple barometer, however, seems to be most in esteem still.

AN instrument contrived in this manner will pretty nearly serve to measure the weight of the atmosphere ; it will not precisely measure its weight, because it is affected also by another property of the air, namely, its elasticity or spring, as we shall see in its proper place. By this instrument we learn, that the air is changing its weight continually, being sometimes more heavy, sometimes more light ; but upon an average, its weight (and spring together) are able to press up a pillar of quicksilver twenty-nine inches and an half high, or a pillar of water thirty-three feet high.

THE atmosphere thus pressing down upon the surface of the earth envelopes all the bodies upon its surface, and presses them together. The whole earth may be considered to suffer as great a pressure

sure from the atmosphere, as if it were pressed on every side by water thirty-three feet deep; and all that are upon the earth's surface are as much pressed on every side as we would be, if instead of an airy atmosphere we had an atmosphere of water, like fishes, thirty-three feet above our heads. The weight of such an atmosphere of water can be easily calculated. A cubic foot of water we will suppose to weigh 60 pounds, 33 feet will weigh 33 times 60, that is 1980 pounds. Suppose a middle-sized man has a surface of about 14 feet square, he will sustain 14 times 1980 pounds of water, that is 27,720 pounds. If a man sustains so much, who is but 14 feet square, how much weight of atmosphere will not the whole earth sustain, which hath a surface of more than two millions of square miles? The student with his multiplication table can readily answer the question. Thus, whether the earth sustains a weight of water thirty-three feet high, or an airy atmosphere equal in

in weight, the difference is nothing, it will be equally pressed by both. Thus, in the atmosphere in which we move with so much freedom, and which we traverse with so much rapidity, we are pressed on all sides with an almost incredible weight, and our bodies seldom support less than twelve ton of air at a time.

So great a pressure of air upon his body may well surprise the ignorant, and shake his belief; but he must consider, that this weight of air he has carried from his earliest infancy. Sensations to which we have been always accustomed, are scarce felt: we cannot perceive the difference of things, when we have no standard by which to measure their variations; we cannot perceive the weight of the air, because we have always felt its weight, and cannot remove from its pressure. No one part of the body can be disturbed by its pressure, for it lays the load equally upon all. Besides this, there

there is air within the body, which serves to counterbalance that from without; and there is another consideration also, which naturalists have passed over unnoticed. The heat of our bodies rarifies the air on their surface; so that in fact an animal doth not sustain so great a pressure from the air as cold inanimate substances are found to sustain. In short, to use the words of Borelli, since by the air's pressure none of the parts of our bodies can suffer either separation, or luxation, or contusion, nor any other change, it is impossible that this pressure can produce any pain.

THIS pressure then can do no injury to the animal frame, we find it by experience of infinite utility. By it the parts of our bodies are kept compactly together, by it the fluids in our vessels are prevented from bursting their canals. Travellers, in ascending high mountains, feel the want of this pressure, to which they were accustomed in the valley:

valley : as they ascend, they perceive a total lassitude upon them from the dilatation of their vessels, and at last the blood begins to burst through the fine coats of the lungs, and they spit blood. The same thing is seen in other animals under the glass receiver of an air-pump : in proportion as the air is exhausted, they pant, swell, vomit, sweat, and generally are unable to retain their abdominal contents.

NOR is the pressure of the atmosphere less serviceable in forcing the parts which fly from bodies upon our sense either of tasting or smelling. The air in a manner forces them down by pressure upon the nerves that serve those senses : for this reason it is, that upon the tops of the highest mountains, (the Peak of Teneriff, for instance) the substances which have the strongest and most pungent taste, such as pepper, ginger, salt, and spirit of wine, are there almost insipid : there perfumes lose their odour, and assafoetida its scent. This arises from
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the want of a sufficient agent to impress the small parts of those bodies, that are continually flying off, either upon the olfactory nerves, or on those of the tongue.

THE pressure of the atmosphere is also equally serviceable to the vegetable world. By it the juices in the tubular parts of vegetables are prevented from bursting their channels, and a proper quantity of air is pressed into them, and thus serves to carry on that continual flow of sap through all their parts, by which means they vegetate. If this pressure is taken away, plants no longer vegetate: the most thriving flower, when conveyed under an air-pump, quickly withers and fades, the air within expanding escapes through the pores of the plant, and leaves its juices deprived of the agent that helps to drive them forward.

IN the inorganized parts of nature this pressure too is entirely necessary; for it

is owing to this pressure that many bodies mix with each other, which they would not do in a void. Thus liquids, such as oils and salts, which mix readily of themselves in the open air, will not, when placed in an air pump, unite with all the art of man. In consequence also of this pressure, and of the air's fluidity, it is that the action of fire is directed from one body upon another, and becomes efficacious. Thus fire in the open air may be applied to wood, and the fire will effectually burn it; but when the same is applied in the exhausted air-pump, the flame will no longer operate upon the wood, for there is then no longer an agent which can press its parts upon the substance which it is set to consume. The same thing will happen if we attempt to dissolve gold in aqua regia. This menstruum ceases to act upon the metal as soon as the air is pumped away. This property of weight in the air also produces the winds, as we shall be led shortly to believe. In short, the weight of the atmosphere, instead of being

being injurious, is our greatest comforter and assistant: when it is heaviest, our spirits are found to be lightest; when by pressing down it drives up the quicksilver in the weather-glass to its greatest height, it is then we feel ourselves invigorated and enlivened. The weather-glass shews us, that in fine weather the atmosphere is then always the most heavy; and yet there are few who do not find themselves on such occasions more alert than in dull weather, when the small pressure the quicksilver sustains evinces that the atmosphere is then most light.

CHAP. VI.

Of the Elasticity or Spring of the Air.

IN the last chapter we only made mention of the weight of the air, and of the effects of its pressure; but this pressure is increased by another cause, I mean the air's spring or elasticity. We explained several appearances in nature that resulted from its pressure; but these appearances were not entirely caused by pressure alone, for the air's elasticity conspired with its weight to work these effects: by the assistance of this property, water rises in pumps, and stands in the barometer.

By the elasticity of the air is meant that property, which this fluid has peculiar only to itself, of yielding to pressure on every side, and then upon the pressure's being taken away, springing out to its former dimensions. Water, which is
6 a fluid,

a fluid, can scarcely be pressed into a smaller compass by all the art of man; nor can quicksilver be compressed: steam, which is a fluid, may be compressed into a smaller space, indeed; but then we destroy its properties: it turns to water, and therefore cannot recover its former dimensions. Air is the only fluid we know that can be pressed into a smaller space than that in which it was contained before, and which, when the force is removed, recovers its former dimensions. Thus the air, for instance, which fills a bladder, might be pressed into the space of a nut-shell. And as the air may be thus compressed into a smaller space, so it can be dilated to fill a larger: the air that fills a bladder, if suffered to expand, would diffuse itself equally, and fill a whole house.

INFINITE are the proofs which may be brought to prove this elastic spring in the air. A bladder, when blown, may be pressed in by the finger; but the air,

upon the removal of the pressure, with true elastic force pushes the part out again. If we place this bladder, almost quite empty, in the receiver of the air-pump, and then exhaust the air from the receiver, the air within the bladder will then exert its power of dilating, the pressure of the external air being taken off, and the bladder, before flaccid, will now appear full, as if just blown up by the breath. A flaccid bladder, carried up to the top of a mountain, will exhibit the same appearance; the air without being more thin at that height, the air within will dilate itself. If instead of putting an half-empty bladder under the air-pump, we should put a blown bladder there, when the void is made around it, the force of the spring of its internal air is too strong for the sides, and the bladder quickly bursts. If, instead of a bladder, we should try the experiment upon glass bubbles filled with air, the effects would be the same: these, like the bladder, would burst in pieces.

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THIS shews the air to be elastic ; but it also shews, that this elasticity is very different from the elasticity of an ivory ball, or a coiled watch-spring, or any such substance, to which the air has been sometimes compared. An ivory ball, when the pressure, which bent its parts inwards, is removed, starts out again to its former size and shape : a watch spring, when the pressure that keeps it coiled is removed, flies out to its former length. But it is very different with a bladder of air : if the pressure is removed from its surface, the air contained not only starts out to fill the same space it occupied before, but ten thousand times that space, if no new pressure prevents it from dilating.

TO account for this surprising force of expansion, of which the air is possessed, has not a little employed the thoughts of the speculative. Some have compared the air to watch springs or hoops, which coiled up by pressure, restore themselves again. Others resembled the air to little flocks

of wool: No more, said they, is necessary, if we would produce elastic air, but to seek it in bodies thus disposed in spiral circles; and bodies, which are most susceptible of this elastic disposition, are such as will most easily furnish air. And for that reason it is, continue they, that liquids cannot be converted into air, because of the roundness and smoothness of their parts.

ALL this, which is obscure enough, has been justly controverted by Newton. The air's extreme expansion to a space an hundred thousand times greater than what it possessed upon pressure, could not be accounted for upon such a bungling mechanism as that of a watch spring, which cannot expand a thousandth part of what we find the air to do. He therefore thinks, that as all bodies have a repulsive power as well as an attractive, this repulsive power always begins to act when the attractive power can reach no farther. Now the parts of the
air,

air, which he supposes to have been solid at first, and which were consequently while solid within the sphere of each other's attraction, being in this case driven asunder by some external interposition, such as fire, or any other agent, no matter what; these parts thus separated lose their attractive and acquire a repulsive force. The parts fly from each other, expand, and fill a sphere almost equal to the extent of imagination: for, to use his own words, "Particles (says he) " when shaken off from bodies by heat " or fermentation, so soon as they are " beyond the reach of the attraction of " the body, recede from it, and also from " one another, with great strength, and " keep at a distance, so as sometimes to " take up a million times more space than " they did before in the form of a dense " body." This vast contraction and expansion seem unintelligible, by feigning the particles of air to be springy and ramous, or rolled up like hoops, or by
(feigning)

(feigning) any other means *than that* of a repulsive power.

As we thus see the particles of air, when the external pressure is removed, fly from each other with such repulsive force, it will be matter of curiosity, and of moment also, to inquire how great that force is, and how much it is diminished, as the particles of air are less pressed together. In the first place, then, Boyle and Mariotte have found by experiment, that the less forcibly they pressed the particles of air together, the less violently did the particles of air repel each other; and so, on the contrary, the more violently they pressed a body of air, the more forcibly did the air resist their pressure, the repelling power of its particles becoming greater the nearer they were driven to each other. Thus, for instance, suppose a gallon of common air were to be pressed into a smaller compass, if a pressure of one hundred pound squeezed
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this air into a pottle, it would require the pressure of two hundred pounds to squeeze it into a quart, the pressure of four hundred pounds to squeeze it into a pint, and so on. But another experiment will lead us still farther, and shew, that the force with which it expands is always equal to the force which presses it. Let us suppose an upright tube thirty inches long, its lower end plunged into a bottle half filled with quicksilver, the mouth of the bottle closed fast round it, and the tube open at top. Let us next imagine a glass receiver, by some contrivance made tall enough to cover this tube, bottle and all, and let the receiver be then exhausted of all its air. The air in the inside bottle, however, cannot be exhausted, for it cannot escape; the mouth is closed fast round the tube, and therefore it must press upon the quicksilver beneath. This it will do, and push it into the tube, whose end was plunged into it, and the air, still continuing to press the quicksilver, will at length press it, merely by
its

its spring or elasticity, as high as it would actually rise in the barometer, by the weight of a pillar of air reaching to the top of the atmosphere. The air's elasticity, therefore, must be equal to the weight; and whatever be the weight or pressure upon any part of the air, its elasticity must be equal to it.

FROM hence then we see, that whatever effects are wrought by the weight of the atmosphere in pressing up quicksilver into the barometer, or into pumps, the spring or elasticity of the air is able to perform the same. Yet we are not for this reason to discard the weight of the atmosphere, and consider it as no way necessary in producing these effects: an opinion some have actually embraced. By no means: it is the weight of the air that gives it its great elasticity; take away the weight, and the elastic force ceases. On the tops of mountains, where this weight is less, the air is less elastic also, and it presses up quicksilver above
three

three inches short of what it is found to do in the valley.

BOYLE was of opinion, that the air, at the surface of the earth, was pressed into almost fourteen thousand times as much less space as it would dilate to by virtue of its own elasticity.

MANY authors have taken pains to calculate into how wide a sphere its particles would diffuse themselves, if suffered to expand at freedom. This inquiry is subject to many difficulties; for to know how much the air would dilate itself, we must consider it as purged from those heterogeneous mixtures, with which we ever find it united. Muschenbroek, from some inconclusive experiments, supposes that the air at the surface of our globe might be dilated so much, as to fill a space four thousand times as large as that it at present usually occupies. Boyle, as I said, affirms, that by means of the air-pump he has rarefied

fied common air so as to fill near fourteen thousand times the space which it occupied before ; but air condensed into its smallest space could fill 50,000 times as much space as it did before. In short, so great is this rarefaction, which can be produced by art, that some have supposed, that if a nut-shell filled with air were suffered to dilate, it would fill all space. This, however, is but mere speculation.

WHETHER air can be infinitely dilated or not, we cannot tell ; and wherever the doctrines of infinity enter into philosophy, knowledge ceases, and we talk at random. This however is certain, that air can be found deprived of its expansive elastic force, and therefore we may readily conceive a point, to which, if it dilates, it ceases to be elastic. Hawkbee has shewn us, that its parts can be so discomposed by violent pressure, that it cannot recover its tone till after some time, and this only by pressing it into water,

ter, and then observing how much time it took to disengage itself. Fontenelle assures us, that humidity in some measure destroys the elasticity of the air for a time; but though the testimony of these naturalists may be controverted, yet that of Hales must confirm us in the opinion: for he deprived the air of its elasticity by the fumes of sulphur, and perhaps there are many natural exhalations which produce the same effect, and therefore, when the air arrives at a certain height, it may cease to expand, and so terminate the surface of our atmosphere.

As the air is thus capable of the most elastic expansion, so is it also of being pressed into a small compass. How far this pressure may reach, or what is the smallest possible degree to which a certain quantity of air may be reduced, has not yet been well ascertained. Halley assures us, from his own experiments, and those of the academy of Cimento,

that the air may be reduced into a space eight hundred times less than what it possessed before in common. Halley, however, has gone much farther than this: by means of freezing it, when mixed with water in an iron ball, he reduced the air into a volume eighteen hundred times less than it had before: so that we see by this means air was condensed into a substance twice as heavy as water, a thing which may excite surprise. Upon this susceptibility of condensation in the air, and its surprising power of expansion, when pressure is removed, has the air-gun been contrived: an instrument by which balls are shot off with the force even of a cannon, by the spring of the air only, and which, without making any report, carry the most sure destruction. The common air-gun is made of brass, and has two barrels. The middle barrel KA (see fig. 50.) from which the bullets are shot, and the larger outside barrel, closed up at the end CD, and in this the

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air

air is driven and kept condensed, by means of a syringe M, which drives the air in, but suffers none to go back. This syringe having been worked for some time, the air is accumulated in great quantities in the external barrel, and this air may be made to strike upon the ball K by means of the trigger O, which pulls back the spiral R, and this spiral opens a valve behind the ball. When the valve is open, the air condensed in the outward barrel rushes in behind the ball, and drives it out with great violence, so great, that at twenty-six yards distance it would drive through an oak board half an inch thick. If the valve behind K be shut suddenly, one charge of condensed air may make several discharges of bullets. The little pellet guns in the hands of children shew also the force and spring of the air; for one pellet stopping the mouth of the gun at one end, and another being driven in at the opposite end, the air contained in the bore of the gun between each pellet is

H 2

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continually condensing, as the hinder pellet is driven towards the foremost, till at last the spring becomes so great as to drive the foremost pellet forward with some noise and violence. In the large air-gun, however, the noise is by no means so great: upon its discharge nothing is heard but a sort of a rushing wind; and it is very possible, that what we are vulgarly told of some men killing others by loading their pistols with dumb powder, might have proceeded from the silent effects of the air-gun.

THIS, however, is but an instrument of curiosity, and sometimes of mischief; but upon the expansive spring of the air it is that the fire-engine has been formed, a machine of the utmost benefit to mankind in one of the most terrible situations. This is used for extinguishing fires; for by means of the spring of the air, which is condensed within the machine, the water is spurted out through a pipe to an height above the top of an ordinary house; for

for water, as we shall see, can be forced in a continued stream not much higher, its parts separating, and the whole dividing into the smallest drops. That the mechanism of the fire-engine, or Newsham's engine, for he was the inventor, may be understood, we must have recourse to the machine in its simplest state, namely, the forcing pump, as it is called. Let us suppose a common water-pump, such as we have already described, DA (see fig. 51.) raising its water through the box H, upon lifting up the piston D. But the piston of the forcing pump differs from that of the common pump, in having no hole through it at *d*, as the other has: so that it will not permit the water in the barrel BC by any means to get above it when it is depressed to B. Therefore the water between the piston *g* and the box H can get neither up nor down, neither through the piston as it is not perforated, nor back through the box H, for the valve there closes against it;

H 3

but

but it has a free passage sideways by the hole *mn* into the pipe *MM*, and this way it goes till it ascends into the air vessel *KK*, up through the pipe at *L*. As it enters at *P*, there is a valve *a*, which permits it readily to enter, but never suffers any to get back. The water then being thus forced into the air vessel *KK*, by repeated strokes of the piston, it rises above the lower end of the pipe *GHI*, and then begins to press the air in the vessel *KK* into a narrower compass, and thus condensing it encreases its spring. For the air has no way to get out of this vessel, the only opening it had was through the hole *I* at the bottom of the tube, and this is now covered up with water. The air therefore is more and more pressed, the more water is forced into the air vessel, till at length it begins to exert its spring against the surface of the water at *H*. This spring therefore forces up the water through the pipe *IHGF*, from whence it spouts in a jet *S* to a great height; and this

this may be continued as long as we chuse to work the machine, and there is any water to supply it. This instrument was in use in miniature as a thing of mere curiosity among naturalists, till the above ingenious and intelligent machinist converted it to the most useful purposes. If we should desire to know, how the water may be driven in one of these instruments, it is obvious, that the more the air in the vessel KK is pressed, the more forcibly will it be driven through the pipe F. If the compression be equal to double the weight of the atmosphere, the spout will be thirty-three feet high; if the compression be three times greater than the weight of the atmosphere, the spout will be (all circumstances the same) sixty-six feet high; if four times, then ninety-nine feet high, and so on. Thus, by encreasing the compression, the water will spout higher, and this compression will be encreased only by lessening the hole, by which the water is to escape from its force, or, in other words, by diminishing

the diameter of the tube. But of this elsewhere,

THUS powerful is the expansive force of the air; but still more powerful would it be if, by means of fire, we encreased the elasticity of its parts, or their aptitude to separate. It is an incontestable truth, that heat will expand air to a most surprising degree. Indeed, heat serves to expand all bodies whatsoever, but by no means in such great proportion as it does air. How heat comes to have this extraordinary power upon air we cannot tell: the causes of many things we are strangers to, and must be contented with knowing the phænomena. Heat expands the air in an amazing degree, and cold, on the contrary, condenses and contracts it. If, in proof of this, I hold a bladder half blown near the fire, the heat will soon encrease the elasticity of the internal air, the bladder will swell, and at last burst. If I place a glass bubble filled with air in the fire, when
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the contents begin to rarefy with heat, the bubble will burst with a loud explosion. So great is this expansion caused in the air by heat, that some have been of opinion, that the air owed its expansive force only to the heat it contained; and as was said in a former chapter, if the air were deprived of all heat, it would quickly be condensed into a solid mass. However this be, Amontons has found, that the heat of boiling water encreased the force of air at least a third part greater than it was before. And he also has proved, that the more dense the air is, the more will an equal degree of heat expand it. If, for instance, a quart of air be condensed into a pint, an heat equal to that of boiling water will operate twice more powerfully upon the compressed pint, than upon the quart that is twice less compressed. Thus we see with what force a small quantity of air may be made to press upon the surface of the earth, its weight from the height of the atmosphere, its elasticity which is equal to

to that weight, and the encreased elasticity which it may receive from being heated. A small quantity of air acting with these three forces conjointly, might be able to cause an earthquake; but whether air thus expanding be actually the cause of earthquakes, we cannot determine: it is probable that it is not; but very possible that it might be.

How great the power of the air is, though only acting with two of these forces, namely, its natural elasticity, and that which it acquires by heat, may be seen in the experiment of a close vessel, which has received the name of Papin's Digester. The effects of this digester are perhaps some of the most surprising that experimental philosophy is capable of exhibiting. The digester is nothing more than an iron vessel of moderate thickness: into this is put meat, bone, hartshorn, or any other animal substance, and then the rest of the vessel is filled with water. Being thus filled, there

there is a cover, which is screwed down close upon the mouth of the vessel, so that no air within the vessel can by any means escape, nor any of the external air enter. Then the whole is placed over the flame of a lamp, or upon a few embers. In less than eight minutes time, the flesh contained will be converted entirely into a liquor like soup. By encreasing the fire a little more, or lengthening the time a few minutes longer, the hardest bones will be dissolved down into a jelly. This utensil was first invented by a philosopher: it is at present chiefly converted to very unphilosophical purposes; for it is merely an instrument of Epicurism and luxury. The French make their soups with it, and we have of late brought it among ourselves from the elaboratory to the larder. When we consider the force which the air must exert in thus bruising down, if I may so say, the hardest bones in a few minutes into an impalpable jelly, it may well excite our surprise.

prise. The heaviest hammer of an iron-work could not do it the fortieth part so soon. This instrument, as we said, is called a Digester, for it was brought by Papin to explain the manner in which our food was digested in the stomach, which he compared to this machine. He found, that in four and twenty hours an heat equal to that of the human body would dissolve the hardest bones in his digester, and he therefore supposed, that the heat in the stomach rarefying the air which was contained in the food, wrought the same change upon it, and dissolved what we eat into a sort of jelly, which is called chyle. A single objection destroyed this whole theory. Fishes have no heat in their stomachs, but yet digest very quickly. This therefore, like several former opinions, was soon abandoned. Boerhaave, finding any one of the former opinions unequal to the explanation of the work of digestion, prudently united them all: a method the fittest,

fittest, if not of satisfying curiosity, at least of concealing ignorance.

WHEN we consider this power, which heat has of rarefying the air, we cannot be so much surpris'd at the constant changes of weight and elasticity, to which we find it liable ; for, setting aside the approach of the sun, the earth is continually sending up hot exhalations, which tend to rarefy the air in some places more than in others. These changes of the air is what, in some measure, carries on the work of vegetation. Let us only conceive the air as closely enveloping the growing plant, and by its elasticity insinuating itself continually into its pores. Its continual dilatation and contraction will therefore take place upon entering the small vessels of the plant ; for as its density is never found in nature two minutes together the same, it will be varying within the plant just as it was before its entrance. Thus in every plant there is a continual vibration of
parts,

parts, the air contracting and dilating with the minutest variations of heat and cold. And thus it is that the juices are driven forward through their channels, and the whole work of vegetation is carried regularly on. And hence also it is, that plants will not vegetate in the void. I have often seen in a clear sunshiny day all the objects of nature as if trembling before my eyes. This is usually ascribed to the rising of vapours; perhaps with more probability it may be attributed to this alternate expansion and contraction of the air. This undulation is very manifest in the spiracles of many plants viewed with the microscope. We find a similar undulation in the parts of light. From analogy we may ascribe such similar motion to the alternate expansion and contraction of the air. At the worst, if it be an error, the error is but small, for the enquiry is of little importance.

C H A P. VII.

Of the Atmosphere and its Height.

WE have seen the manner in which the air suspends quicksilver in the empty tube to the height of about twenty-nine inches, and water to the height of about thirty-two feet: the quicksilver or water, however, as we said, does not always rise to the same height: the quicksilver, for instance, alters so as to be three inches lower, or three inches higher, at one time than at another. So that in the barometer or weather-glass there is a variation of three inches at least between its highest and its lowest suspension. These changes, as we also observed, must be ascribed to the alteration of the weight of the air, sometimes pressing the external quicksilver with greater, sometimes with lesser force. If the quicksilver always stood at the same height, that is, exactly at twenty-nine
nine

nine inches, the weight of a pillar of the atmosphere would be concluded to be invariable; and, as we shewed before, would be equal to a pillar of quicksilver twenty-nine inches high, and it would weigh above thirty thousand pounds; but as the barometer is continually altering, it is plain the weight of the atmosphere is altering also, insomuch that it is near one tenth more heavy at one time than at another. For suppose, when the air is lightest, we at one time sustain a weight equal to a pillar of quicksilver twenty-eight inches high, it is obvious that when, at another time, this pillar is encreased by three inches of quicksilver more, this will make our load near one tenth part more; or, in other words, if we at one time sustain a pillar of air equal in weight to twenty-eight of these inches, which in round numbers is near thirty thousand pound, we shall at another time, when the air is heaviest, be loaded with a pillar of air equal to thirty-one inches of quicksilver, which will add
to

to our load of thirty thousand pound, near one tenth, that is, make it thirty-three thousand pound.

SUCH is the difference of weight, which we insensibly sustain at one time more than at another. Of the encrease of this pressure other animals seem much more sensible than we: crows, for instance, as the poet has remarked, by their cawing surely foretel a change of weather: their more poignant sensations discover the approaching alteration, which perhaps the luxury, and artificial heats, to which we have accustomed ourselves, have deprived us of. Certain it is, that in some parts of India, where the Joquefe priests never eat animal food, nor ever enter houses, their sensations of approaching change in the weather are said to be exquisite: they feel its weight, and their smell discovers its alterations. It is common among them, when describing the beauties of a place, to rank

among the number the exquisite *taste* of its air.

WE have already observed, that the greatness of the atmosphere's weight did not affect us with a sense of any oppression, and we may remark the same with regard to the encrease of this weight. Nature hath wisely armed us against this change, and in proportion as the atmosphere is laid upon us with additional oppression, the heart beats quicker against it, and drives the compressed fluids of the body with greater force. Why the heart thus bounds more strongly when the weight of the atmosphere is greatest, we can but obscurely tell: it is an enquiry rather belonging to the medical physiologist, than to the natural philosopher. To whomsoever it belongs, the investigation is abstruse, and the solution difficult.

As we know with some precision the weight of our atmosphere, so some philosophers

losophers have pursued speculation, and attempted to discover its height also. Geometricians love to pursue a subject where calculation is all that is necessary; for this reason we have had many solutions of this question, and all different from each other.

IF the air was not elastic, but throughout of the same density from the surface of the earth to the top of the atmosphere, like water, which is equally dense at every height, it would then be an easy task to measure the height of the atmosphere. We might then proceed certainly and safely thus. We have only to find out the proportion between the height of a short pillar of air, and a small pillar of water of equal weight; and having compared the proportion the heights of these bear to each other in the small, the same proportion will be sure to hold in the great, between a pillar of water thirty-two feet high, and a pillar of air that reaches to the top of the atmosphere,

sphere, whose height I want to know. Thus, for instance, we find that a certain weight of water reaches one inch high, and a similar weight of air reaches seventy-two feet high: this then is the proportion two such pillars bear to each other in the small. Now, if one inch of water be equal to seventy-two feet of air, to how much air will thirty-two feet of water be equal. By the common rule of proportion, I readily find, that thirty-two feet, or 384 inches of water, will be equal to 331,776 inches, which makes something more than five miles, which would be the height of the atmosphere, were its density every where the same as at the earth, where seventy-two feet of air were equal to one inch of water.

BUT this is not really the case; for the air's density, as we shewed before, is not every where the same, but decreases as the pressure upon it decreases; so that the air becomes lighter and lighter the
6 higher

higher we ascend, and at the upper part of the atmosphere, where the pressure is scarce any thing at all, the air dilating in proportion, must be expanded to a surprising degree; and therefore the height of the atmosphere must be much greater than has appeared by the last calculation, in which its density was supposed to be every where as great as at the surface of the earth. In order therefore to determine the height of the atmosphere more exactly, geometers have endeavoured to determine the density of the air at different distances from the earth. The following sketch will give an idea of the method which some geometers have taken to determine this density, which is preparatory to finding out the height of the atmosphere more exactly.

LET us suppose a pillar of air to reach from the top of the atmosphere down to the earth's surface; and let us also suppose it marked like a standard by inches, from the top to the bottom; let us still

farther suppose, that each inch of air, if not at all compressed, would weigh one grain. The topmost inch then weighs one grain, as it suffers no compressure whatsoever; the second inch is pressed by the topmost with a weight of one grain, and this added to its own natural weight or density of one grain, now makes its density, which is ever equal to the pressure, two grains. The third inch is pressed down by the weight of the two inches above it, whose weights united make three grains, and these added to its natural weight, give it a density of four grains. The fourth inch is pressed by the united weight of the three above it, which together make seven grains, and this added to its natural weight give it a density of eight grains. The fifth inch, being pressed by all the former fifteen, and its own weight, added, gives it a density of sixteen grains, and so on, descending downwards to the bottom. The first inch has a density of one, the second inch a density

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sity of two, the third inch, a density of four, the fourth inch of eight, the fifth of sixteen, and so on. Thus the inches of air increase in density as they descend from the top, at the rate of one, two, four, eight, sixteen, thirty-two, sixty-four, and so on, which is called a geometrical progression. Or if we have a mind to take this backwards, and begin at the bottom, we may say, that the density of each of these inches grows less upwards in a geometrical progression. If, instead of inches, we suppose the parts into which this pillar of air is divided to be extremely small, like those of air, the rule will hold good in these as well as those. So that we may generally assert, that the density of the air, from the surface of the earth, decreases in a geometrical proportion.

THIS being understood, should I now desire to know the density of the air at any certain height, I have only first to find out how much the density of the air

is diminished to a certain standard height, and from thence proceed to tell how much it will be diminished at the greatest heights that can be imagined. At small heights the diminution of its density is by fractional or broken numbers. We will suppose at once then, for greater ease, that at the height of five miles, or a Dutch league, the air is twice less dense than at the surface of the earth: then, at two leagues high, it must be four times thinner and less dense, and at three leagues eight times thinner and lighter, and so on. Instead of Dutch leagues, suppose we took a German league of seven miles, and that it was four times less dense at the height of the first German league, then it would decrease in the same proportion, and be four times less dense than the first at the second league, that is sixteen times; and four times less dense than the second at the third league, that is sixty-four times; and four times less dense than the third at the fourth league, that is two hundred and fifty-six times

times less dense than at the surface. In short, whatever decrease it received in the first step, it will continue to have in the same proportion in the second, third, and so on; and this, as we said, is called geometrical progression. They who are fond of calculations may go still forward, calculating the height of the air in this manner, and they will find, that a cubic inch of such air as we breathe here below would be so very much rarefied at the height of five hundred miles, that it would fill a sphere equal in magnitude to the farthest reach of our planetary system. Calculations, however, confer but little wisdom.

By this method of calculating the density of the air, we find that the height of the atmosphere is scarce to be determined, as it grows thinner the higher it ascends. However, I think it may be easily enough proved, that it cannot diffuse itself above a certain determined height; for it must be noted, that the air is attracted by gravity to the earth,
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all the time it is thus impelled to recede from it by its expansive force. Now, if its density, and consequently its expansive force, which is equal, be ninety hundred thousand million times less at one hundred miles from the earth, than at its surface, as is nearly the case; and if, on the other hand, the power of gravity should be but a single tenth part less at an hundred miles distance, than it is at the surface of the earth, it is evident, that the power of gravity will become at last greater than the force of expansion, and at a certain height the air, instead of suffering farther expansion, will be attracted towards the earth. For instance, suppose a bubble of air at the surface of the earth weighs but the millionth part of a grain, suppose it raised seventy miles high, its weight or gravity will scarce be diminished at all, but its density, and consequently its expansive force, will be a million times less than before. Suppose then it is raised seventy-seven miles high, this will make scarce any alteration in its gravity; but its
density

density, and consequently its expansive force, will be four million times less. Here then the gravitating force exceeds the expansive force by three millions, and consequently the particles of air, instead of attempting to rise by expansion, will be carried down by the superior force of gravity. In other words, the atmosphere cannot rise above seventy miles high at the most.

It were to be wished, that this theory were ascertained by experiment, and that upon examining the diminution of the air's density at three different heights, as in the valley, on the brow of a high mountain, and on its summit, we found the density of the air thus decreasing in geometrical proportion. Were the theory thus incontestably ascertained, and found conformable to facts, we might easily measure the heights of mountains merely by knowing the density of the air, and the air's density could always be easily found by the barometer. Derham, if I remember right, was the first who thought
upon

upon this method of measuring the heights of mountains by the barometer. He attempted to measure the hill of Snowdon in this manner: however, he supposed the atmosphere of an equal density throughout. Others have taken its geometrically decreasing density into consideration, and laid down rules for thus measuring mountains by calculating their heights, in proportion to the decrease of the air's density. The thing is easily enough done; but at present, the whole of the method is looked upon as matter rather curious than either useful or exact. Cassini the younger, in his admeasurement of a degree in France, calculated the densities of the air at several heights, upon different mountains; and he found the density of the air decrease in a much greater proportion as he ascended, than in the geometrical progression which the theory had laid down. The publication of these experiments caused a schism among naturalists. Some have ascribed this difference between experiment and theory to the vapours being

being in greater abundance in the valley than on the mountain, and as these vapours neither rise to the heights of pure air, nor act with equal elasticity, the air upon the tops of mountains being freed from these is more expanded, and consequently less dense. This is denied by others, particularly Fontenelle: he asserts, that the air is more rare upon the tops of mountains, because there it has more elasticity, and it has there more elasticity because it has more humidity; but Dr. Jurin has well confuted this by shewing, that humidity by no means increases the elasticity of the air. Others there are, who make a distinction between the air on the mountain, and the air in the valley, and who think that they are governed by different laws. Such is the state of the controversy as it still subsists. Philosophers dispute, but chance more frequently decides.

THIS method of determining the height of the atmosphere, though perhaps

haps the best, is yet disliked by Bernouilli, who gives us a method of his own. The heat in the air is reckoned by him as one of the agents in producing its different densities. This method, however, is not much followed: the manner of finding out its height, as given by Kepler, is most known and followed, though perhaps built, like the rest, upon a baseless foundation. Kepler's method is this.

ASTRONOMERS know, to the greatest exactness, the place of the heavens in which the sun is at any one moment of time: they know, for instance, the moment in which it will set, and also the precise time in which it is about to rise. However, upon awaiting his appearance any morning, they always see the light of the sun before its body, and they see the sun itself some minutes sooner above the mountain top, than it ought to appear from their calculations. Twilight they see long before the sun appears,

appears, and that at a time when they know that it is eighteen degrees lower than the verge of the sky. There is then in this case something which deceives our sight; for we cannot suppose the sun to be so irregular in his motions as to vary every morning: this would disturb the regularity of nature. The deception actually exists in the atmosphere. By looking through this dense, transparent substance, every celestial object that lies beyond it is seemingly raised up, in some such manner as we see a piece of money look as if raised higher in a basin filled with water. From hence it is plain, that if the atmosphere were away, the sun's light would not be brought to view so long in the morning before the sun itself actually appears. The sun, without the atmosphere, would appear all blazing in light the instant it rose, and leave us in total darkness the instant of its setting. The length of the twilight, therefore, is in proportion to the height of the atmosphere; or let us
invert

invert this and say, that the height of the atmosphere is in proportion to the length of the twilight. So that the distance there is between the real and the apparent place of the sun's ray will serve to measure the height of the atmosphere; for let us suppose the sun to be at S, and the eye of a spectator upon the earth at A. Now the spectator cannot see the sun, but yet he will see the light reflected by the atmosphere; for when the ray of the sun touches the earth at D, (see fig. 52.) and goes still forward, as soon as it arrives at B it will bend slanting to the spectator's eye at A; by which he enjoys the light before the sun appears. This ray has touched the earth at D and at A, and the arch DA is comprehended between the two tangents. If a line be drawn from the centre of the earth, so as to divide this arch in two equal parts, from the nature of all circles, as geometry assures us, it must come upon the place where the ray was bended at B, and the length of the line HB will be the height of the atmosphere,

sphere, which even a common surveyor may easily find. It is generally found by this means to be about forty-five miles high. All this holds, supposing the rays to be straight or direct as they pass through the atmosphere, which in fact they are not. Kepler was the first who found out this, but he soon abandoned it, because it made the atmosphere many times higher than he really thought it was.

HOWEVER this be, twilight is one of the great blessings we derive from our atmosphere: by it we are by gentle degrees brought from darkness into light, and again from light into darkness. In those countries towards the poles, where, though the sun disappears totally for a season, yet, when not above eighteen degrees below their horizon, they have the twilight all night long. At the equator, the twilight is shortest, because the rays of the sun dart most directly through the atmosphere, and consequently are less refracted by passing through

it; but even allowing the whole of this computation to be exact, which however the learned now begin to doubt of, yet there must be allowance still made for the alterations in the density of the atmosphere; for the denser it is, the greater will be its power of refracting the light, and we shewed before that cold will encrease its density. In Nova Zembla, where the air is extremely cold, the refracting power of the atmosphere is so great, that some Hollanders, who wintered there, were surpris'd to see the sun seventeen days before they expected to see him, even allowing for the influence of the atmosphere, as astronomers usually do. There is another appearance in the heavens usually ascribed to the atmosphere, the largeness of the rising or setting sun or moon, and their oval appearance; but as these can be explained only by the assistance of optics, they must be reserved for that part of natural philosophy.

BESIDE

BESIDE these benefits which we derive from our atmosphere, must be mentioned that of its surrounding the earth on every side, and turning with it as the earth turns. Were it not for this, the tenants of the earth's surface might be every moment liable, perhaps, to the shocks of that fine fluid with which our planetary system is, by most moderns, thought to be filled. The parts of light itself might make a violent impression upon us, if we were dashed against them by the earth's rapid rotation, unshielded by our atmosphere.

CHAP. VIII.

Of WINDS.

WE have already represented the atmosphere as in continual motion, alternately relaxed by heat, and contracted by cold, as the sun, our source of celestial heat, acts upon it, or the hot or cold exhalations from the earth contribute to encrease its warmth or to diminish it.

IF we should move with great speed against the air, we should feel its force: the same thing will happen if the air moves with swiftness against us: we feel it forcibly impressed upon our bodies, and the air thus moving all know to be called Wind. The wind is nothing else but the air put violently into motion, and the more swift this motion, and the more dense the air, the greater the wind's force, and if to a great degree, it is then called a Storm.

IF

IF we suppose the atmosphere heated in any one part more violently than in another, it is plain, that this will dilate it, and drive the air out of that part. The air, however, cannot be thus driven from its own peculiar place without making an excursion into the place which another body of air possesses. By this means a great quantity of air will be crowded or condensed into one particular region, while another shall have but very little. This inequality of the air in these two different regions must continue as long as the one of them continues more heated by the sun or by vapours than the other. But when the cause of the inequality is removed, and the heat is equally moderate in both places, the air condensed in one place having nothing now to resist its pressure, will rush into the place empty of air, and thus flowing in with a violent motion produce winds, such as we every hour experience. To have a clear conception of this, let us compare that particular spot or place where all the

air is just in a manner exhausted by heat to a great empty gulf, into which fluids are going to enter from every side. The inhabitants in the midst of the gulf are pressed violently by the stream on every side: those who are to the north of it, see the stream of air directed towards the south, that is, they have a north wind: those on the contrary, who live to the southward, see the stream going northwards, and therefore have a south wind, and so of all the other points of the compass. In the midst of the gulf, where all the streams meet and mix, they feel all the inconveniences which are the effects of that heterogeneous mixture. There sulphureous exhalations from the south, torrents of nitre from the north, and watery vapours from every side, are indiscriminately blended together in one confused mass. From hence proceed tempests, thunder, rain, hail, and whirlwinds.

BUT though winds are thus found to produce mischief, yet the harm they

do bears no proportion to the good we experience from them. The atmosphere of a large city, if continually the same, would soon become corrupt, and from the quantity of animal exhalations floating in it, would in a very few days, perhaps hours, destroy the health of the inhabitants. The wind prevents this, and blows away this over-charged part of the atmosphere, placing a new column of atmosphere in its room.

THESE currents of air are also beneficial in another respect, for they often cool the atmosphere when too much heated. Those places, which have but just before felt the most violent effects of heat, are refreshed by the air which comes from a colder region. On the other hand, the air, which by heat has been forced from the warmer region into that which is more cold, reciprocally benefits that, and softens the severity of its natural atmosphere. The inhabitants of those islands that lie in hot tropical cli-

mates feel these benefits most signally from the wind. All day the sun beating with severity against the solid earth of the island, causes this, like all hard substances, to be greatly heated, and the air consequently rarefied to a great degree. In the mean time, the air upon the surface of so great and so fluid a body as the surrounding ocean, is by no means so much rarefied, but lies out cool at sea, and consequently healthful. As soon, therefore, as the sun every day has done exerting the violence of his heat, the air from the ocean pours in upon the inhabitants panting and faint for want of air, and at once comforts, cools, and refreshes them. Thus every four-and-twenty hours they have two regular and stated winds. In the morning, while the sun is driving off the air from land, the wind blows out to sea; on the contrary, when the sun's power is over, and he has done his task, at night the air from the sea rushes back to fill the space the sun had made empty.

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IN this manner, however irregular we find the wind in this still happier climate, they have it a more constant and more grateful visitant; yet the constancy of the wind among the islands is but a trifle, if compared to what it is found to blow in the open parts of the ocean between the tropics; for in general, within the whole torrid zone, an east wind is found to prevail throughout the whole year: so that if a ship should sail away from the coast of Africa, and go continually westward, it would have an eastern gale to carry it round the whole globe. From its being so favourable to navigation, this wind has been called a Trade Wind.

THE cause of this constancy in the trade winds has been variously accounted for. Very many, and very absurd have been the conjectures brought to explain them. There is a weed, says Lyfter, growing in the sea, called *alga marina*, and extremely abundant in the

the tropical climates. The perspirations of this weed produce air, and this air produces the trade winds, and these trade winds are always constant, because they are always produced from the same plant. This is sufficiently absurd.

DR. GORDON, with more probability, ascribed the trade wind to the motion of the earth upon its axle; but none of the motions of a fluid at the earth's surface can be ascribed to that cause. Others were willing to ascribe them to the same causes that produced the tides, the sun and moon's attraction. But it might be geometrically proved, that this attraction would not cause the air to rise much higher than it does the ocean, which in the air would be so trifling a difference, that it could cause no sensible alteration whatever in the direction of the winds. It is to Dr. Halley we owe the most rational theory upon this subject.

HE

HE explains the cause of the trade-winds in general terms thus: the air is more rarefied between the tropics, because a greater quantity of the sun's rays fall in that region, and because they fall more directly, and also because it is that part of the earth which is actually nearer the sun. Now, as the sun travels onward from east to west every day, he dilates most that part of the atmosphere that is immediately under him, and so makes a kind of a void space as he goes along; but it is very obvious, that the air behind him will rush in to fill up this space that he has just left, rather than the air which is before his motion: for if the air before his motion rushed forward to fill up the chasm he has just made, it must pass directly under his rays, and if so it would itself by that means be dilated, and so rendered unfit to fill up the void place it was rushing in to occupy. For this reason, therefore, the air must follow the sun's motion, and fill each chasm he has just made; in other words,
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the trade-winds must move from east to west. From hence, therefore, between the tropics, there would always be a current of air due east; but we are to take another effect into consideration. The dense air from the north and south poles is always rushing into the rarefied regions of the equator. Here these two opposite winds meeting with that which continually blows due east, they in some measure flow in its current, and in some measure keep their own current. On the north side of the equator the wind blows north-east; on the south side of the equator it constantly blows south-east; and this is really the case with the trade-winds, which lie over the open part of the ocean, and which are not affected by the heat, which the sun striking against some neighbouring continent might produce.

I SAY in the open parts of the ocean; for in those parts of it crowded with islands, or lying near continents, the trade-winds are by no means so regular. Earth is a more hard body than water;

hard bodies receive a stronger heat than those which are fluid; an iron heated red-hot is much hotter than water at its highest pitch of heat; the earth, as being an harder body than the ocean, receives more of the sun's rays, and reflects them with greater violence. Thus the air over a large continent is much more heated, and therefore more dilated, than over an ocean. This difference, therefore, produces what mariners in those climates call the Land-wind. Every day, while the sun heats the earth, and thus produces a dilatation, the air is in a manner driven out to sea; but at night, when this heat ceases, the sea-breeze blows in upon land to fill up the void caused by the diurnal solar heat. Thus it is where there are continents, or islands, lying between the tropics: by day the wind blows out from shore; by night, it blows back again the contrary way, and mariners find it dangerous to attempt landing at that time; but it is otherwise where the ocean is open. Such
is

is the regularity of the trade-winds, in such circumstances, that from the most western coast of America across the great Pacific Ocean to the Philippine Islands, is but a voyage of nine weeks; for the ocean is almost without island, and the winds upon its surface blow continually the same way.

SUCH therefore is the nature of the winds, that if the earth were all over covered with one deep ocean, the winds upon its surface would always blow the same way on either side of the equator, and the motion of the air would regularly pursue the motion of the sun; but in the earth's present state, there are numberless causes to interrupt their regularity, and more in our colder climates than in those burning regions that are more immediately subject to the sun's influence. In these there is a kind of interrupted regularity in the winds, but with us nothing can be more irregular than they are. The sun is seldom so
extremely

extremely powerful in the temperate zone, as to counteract the inconstant and uncertain impressions of different exhalations upon the wind, and thus give regularity to its motions. Vapours, meteors, mountains, forests, lakes, cities, all conspire to give a new direction to the current of the air, and alter the state of the atmosphere. The causes that give irregularity to winds with us are numerous, while the sun, that in the torrid climates regulates their motion, operates here with diminished influence. We have not yet, therefore, a sufficient history of the changes wrought by these different causes upon the wind in our own climates ; and until such an history, which must be the work of more than an age, can be compiled, no certainty is to be expected in our predictions of the changes it may undergo. Bacon was the first who undertook to write an history of the wind : his great spirit was deterred at no difficulty in the way ; he began the edifice, and succeeding philosophers,

sophers, instead of pursuing his great design, have left it standing just at the height he left it. They have added scarce any new observations to enlarge the work. Had his plan been carried on with the same spirit with which he began it, the variations of the weather might now perhaps have been determined with greater certainty, and who knows but by this time we might have been able to predict a north or a south wind, with as much exactness as we now calculate an eclipse. To predict an eclipse is an object merely of curiosity; to predict an approaching storm would be of inconceivable benefit. The time spent in determining the figure of a *tautochrone* might have been more usefully employed in this research. I shall conclude this chapter with the sketch of an history of the winds, such as he has left it, with some few additions by Halley, Buffon, D'Alembert, and others.

AT

AT sea the winds are more regular than at land ; for there nothing opposes their progress, or alters the sun's influence.

THE air at sea is more equable, as well as more constant : at land it blows in fits of force and intermission ; but at sea the current is strong, steady, and even.

IN general, at sea, on this side the equator, the east and north winds are most violent and boisterous : on the contrary, at land, the west and south winds are most subject to produce hurricanes and tempests.

THE air is often seen to move in two contrary currents, and this almost ever previous to thunder. The clouds, in such a case, are seen to move one way, while the weathercock points another.

THE winds are more violent at certain heights than upon the plain, and the higher we ascend lofty mountains, the greater is the force of the wind, till we get above the ordinary heights of the clouds. Above this the sky is usually serene and clear. The reason is, that the wind, at the surface of the earth, is continually interrupted by hills and risings: so that, on the plain, between any two of these, the inhabitants are in a kind of shelter; but when once the interposition of small hills no longer stops the wind's course, it then becomes stronger, as the interruptions it meets with are fewer. At the tops of the higher mountains its interruptions are least of all; but it does not blow with violence there: for its density is so much diminished by the height, that its force is scarce perceivable, and the storm falls midway below.

A current of air always augments in force in proportion as the passage through which

which it runs is diminished. The law of this augmentation is, that the air's force is compounded of its swiftness and density, and as these are encreased, so will the force of the wind. If any quantity of wind moves with twice the swiftness of a similar quantity, it will be twice as forceful; but if, at the same time that it is twice as swift, it moves through twice a smaller tube, and the sides of the canal give no resistance to its motion, it will be four times as forceful. This, however, is not entirely the case; for the sides of the tube give a resistance, and retard its motion, in a proportion that is not easily calculated. From this increase of the wind's density in blowing through narrow passages, it is that we see the storms so very violent that sometime blow between two neighbouring hills. It is from this, that when caught in long arcades opening at one end, the wind blows with great force along them. From this increased density it is, that we meet with such cold

blasts at the corners of streets. In short, whatever diminishes its bulk, without taking entirely away from its motion, increases the vehemence of the wind. This also is the reason why the air reflected back from the side of a mountain is often more violent than the air which first struck its side ; for it is by this means condensed, and its force augmented. The countrymen and farmers have a distinction which is not without its foundation ; for they make a difference between a swift and an heavy storm : the swift storm is loud, boisterous, and inoffensive ; the heavy storm more so, but more forceful and dangerous. This shews the insufficiency of those instruments made for measuring winds, by measuring the rapidity only with which they move. These machines for measuring the swiftness of the wind are called Anemometers, an ill-sounding word made from Greek.

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MR. BUFFON has divided the winds by zones: the frigid zone is the parent of north winds, and east winds rule at the equator. The winds of the temperate zone are composed of the eddies of these two united. As the north wind prevails over the east wind, it produces a west wind; as the east wind prevails, it produces a wind from the south. These, however, are reflected, refracted, and at last destroyed by each other's opposition in every region: their force is greatest when several winds conspire to move in the same current.

So much may serve as a sketch of this great undertaking. It is but very lately that we began to make observations on the changes of the weather: which may be considered as a noble and disinterested present to posterity; for we can scarce expect to have them in sufficient number in our own age, from whence to deduce any general theory that shall turn to public benefit.

C H A P IX.

Of Musical Sounds.

THE sense of sounds adds infinitely more to the happiness of man than to that of all other animals: it not only supplies him, like them, with expressions of his wants and his desires, but it opens to him a wide field for pleasure. He finds delights unknown to the rest of the animated creation from their varied combinations. The fables of the ancients pretend, that music was first found out by the beating of different hammers upon the smith's anvil. Without pursuing the fable, let us endeavour to explain the nature of musical sounds by a similar method; for fable may often conduct us to truth. Let us suppose an anvil, or several similar anvils, to be struck upon by several hammers of different weights or forces. The hammer, which
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is double that of another, upon striking the anvil will produce a sound double that of the other: this double sound musicians have agreed to call an Octave. The ear can judge of the difference or resemblance of these sounds with great ease, the numbers being as one and two, and therefore very readily compared. Suppose that an hammer three times less than the first, strikes the anvil, the sound produced by this will be three times less than the first: so that the ear, in judging the similitude of these sounds, will find somewhat more difficulty; because it is not so easy to tell how often one is contained in three, as it is to tell how often it is contained in two. Again, suppose that an hammer four times less than the first strikes the anvil, the ear will find greater difficulty still in judging precisely the difference of the sounds; for the difference of the numbers four and one cannot so soon be determined with precision as three and one. If the hammer be five

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times

times less, the difficulty of judging will be still greater. If the hammer be six times less, the difficulty still increases, and so also of the seventh, insomuch that the ear cannot always readily and at once determine the precise gradation. Now, of all comparisons, those which the mind makes most easily, and with least labour, are the most pleasing. There is a certain regularity in the human soul, by which it finds happiness in exact and striking and easily-made comparisons. As the ear is but an instrument of the mind, it is therefore most pleased with the combination of any two sounds, the differences of which it can most readily distinguish. It is more pleased with the concord of two sounds, which are to each other as one and two, than of two sounds, which are as one and three, or one and four, or one and five, or one and six or seven. Upon this pleasure, which the mind takes in comparison, all harmony depends. The variety of sounds are infinite; but because the ear cannot com-
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pare two sounds so as readily to distinguish their discriminations when they exceed the proportion of one and seven, musicians have been content to confine all harmony within that compass, and allowed but seven notes in musical composition.

LET us now then suppose a stringed instrument fitted up in the order mentioned above. For instance: let the first string be twice as long as the second; let the third string be three times shorter than the first, let the fourth be four times, the fifth string five times, and the sixth six times as short as the first. Such an instrument would probably give us a representation of the lyre as it came first from the hand of the inventor. This instrument will give us all the seven notes following each other, in the order in which any two of them will accord together most pleasingly; but yet it will be a very inconvenient and a very disagreeable instrument: inconvenient,
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for in a compass of seven strings only the first must be seven times as long as the last; and disagreeable, because this first string will be seven times as loud also: so that when the tones are to be played in a different order, loud and soft sounds would be intermixed with most disgusting alternations. In order to improve the first instrument, therefore, succeeding musicians very judiciously threw in all the other strings between the two first, or, in other words, between the two octaves, giving to each, however, the same proportion to what it would have had in the first natural instrument. This made the instrument more portable, and the sounds more even and pleasing. They therefore disposed the sounds between the octave in their natural order, and gave each its own proportional dimensions. It is not my design here to enter farther into this subject than merely its slightest elements; let it therefore suffice to say that, in general, of these sounds, where the proportion

portion between any two of them is most obvious, the concord between them will be most pleasing. Thus octaves, which are as two to one, have a most harmonious effect; the fourth and fifth also sound sweetly together, and they will be found, upon calculation, to bear the same proportion to each other that octaves do. “Let it not be supposed, (says Mr. Saver) that the musical scale is merely “an arbitrary combination of sounds: “it is made up from the consonance “and differences of the parts which “compose it. Those who have often “heard a fourth and a fifth accord together, will be naturally led to discover “their difference at once; and the mind “unites itself to their beauties.” Let us then cease to assign the coincidences of vibrations as the cause of harmony, since these coincidences in two strings vibrating at different intervals, must at best be but fortuitous, whereas concord is always pleasing. The true cause why concord is pleasing, must arise from our power,

power, in such a case, of measuring more easily the differences of the tones. In proportion as the note can be measured with its fundamental tone by large and obvious distinctions, then the concord is most pleasing; on the contrary, when the ear measures the discriminations of two tones by very small parts, or cannot measure them at all, it loses the beauty of their resemblance: the whole is discord and pain.

BUT there is another property in the vibration of a musical string not yet taken notice of, and which serves to confirm the foregoing theory. If we strike the string of an harpsichord, or any other elastic sounding cord whatever, it returns a continuing sound. This till of late was considered as one simple uniform tone; but all musicians now confess, that instead of one tone it actually returns four tones, and that constantly. The notes are, beside the fundamental tone, an octave above, a twelfth above,

above, and a seventeenth. One of the base notes of an harpsichord has been dissected in this manner by Mr. Rameau, and the actual existence of these tones proved beyond a possibility of being controverted. In fact, the experiment is easily tried; for if we smartly strike one of the lower keys of an harpsichord, and then take the finger briskly away, a tolerable ear will be able to distinguish, that after the fundamental tone has ceased, three other shriller tones will be distinctly heard: first the octave above, then the twelfth, and lastly the seventeenth: the octave above is in general almost mixed with the fundamental tone, so as not to be easily perceived, except by an ear long habituated to the minute discriminations of sounds. So that we may observe, that the smallest tone is heard last, and the deepest or largest tone first: the two others in order.

In the whole theory of sounds, nothing has given greater room for speculation, conjecture,

conjecture, and disappointment, than this amazing property in elastic strings. The whole string is universally acknowledged to be in vibration in all its parts, yet this single vibration returns no less than four different sounds. They who account for the tones of strings by the number of their vibrations are here at the greatest loss. Daniel Bernouilli supposes, that a vibrating string divides itself into a number of curves, each of which has a peculiar vibration, and though they all swing together in the common vibration, yet each vibrates within itself. This opinion, which was supported, as most geometrical speculations are, with the parade of demonstration, was only born soon after to die. Others have ascribed this to an elastic difference in the parts of the air, each of which, at different intervals, thus received different impressions from the string, in proportion to their elasticity. This is absurd. If we allow the difference of tone to proceed from the force, and not the
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the frequency of the vibrations, this difficulty will admit of an easy solution. These sounds, though they seem to exist together in the string, actually follow each other in succession: while the vibration has greatest force, the fundamental tone is brought forward: the force of the vibration decaying, the octave is produced, but almost only instantaneously; to this succeeds, with diminished force, the twelfth, and lastly the seventeenth is heard to vibrate with great distinctness, while the three other tones are always silent. These sounds, thus excited, are all of them the harmonic tones, whose differences from the fundamental tone are, as we said, strong and distinct. On the other hand, the discordant tones cannot be heard, their differences being but very small are overpowered, and in a manner drowned in the tones of superior difference: yet not always neither; for Daniel Bernouilli has been able, from the same stroke, to make the same string bring out its harmonic

monic and its discordant tones also*. So that from hence we may justly infer, that every note whatsoever is only a succession of tones, and that those are most distinctly heard, whose differences are most easily perceivable. Thus far then we see a strong similitude between a tone of sound and a ray of light: both are, to all appearance, simple and uniform; but art can dissect them, and in some measure discover their constituent principles.

I WOULD only observe here farther, that of all the sounds I have hitherto experienced, those brought from the edge of the musical glass are most simple and uniform. The great pleasure they give is from their simplicity alone; for when three, or any other number of them, come to be united together into one harmony, the sounds are low, trifling, confused, and scarce supe-

* Vid. Memoires de l'Académie de Berlin, 1753, p. 153.

rior to that of a jews-harp. So that we see how injudiciously the performers on glasses manage, who play firsts, seconds, and sometimes a base altogether upon an instrument, whose only excellence depends, not on its strength, but its simplicity of tone.

To recapitulate all that has been said upon the subject of sounds: long continued tones are nothing more than a repetition of the same stroke and tone. By swiftly repeating the strokes, all bodies are capable of giving tones; but these tones do not arise from the swiftness but the greatness of the blow. The tone, therefore, in elastic strings, is not to be attributed to the frequency of the vibration, but to its force, to that greater vehemence with which a long and thick string, permitted by proper tension to exert its whole elastic power, excels a short and small string screwed up almost beyond its pitch of elasticity. The quantity of vibration is always proportioned

to the length, diameter, and diminished tension of the string; but the quantity or depth of tone is not always so. Yet, notwithstanding this, in practically tuning most musical instruments, as the tone and vibrations arise from the same cause, and are usually similar, the vibrations will serve to measure the tone. But then, when we consider the subject philosophically, we should not call those vibrations the parent, when they are only the sister of musical sounds. Light and flame are ever seen together, and yet it would be unjust to say that light is the parent of flame. True thinking is nothing more than giving effects their proper causes.

I CANNOT quit a subject relative to an art, of which I am so fond, without making a few slight remarks upon English musical composition in general. Foreigners greatly object to our harmonies: they accuse them of being almost always

always overcharged, and that there is never room enough left for occasional force of expression. Whether their dislike to Handel be just or not, I will not pretend to determine; but certain it is, they seem highly displeased with his stile and manner, nor will they bear to hear him named with Haffé, Pergolese, Faradellas, or any of the principal foreign composers. The fire of his music, as they express it, is much too great, and generally unfitted to the subject and the performers. They should have considered, however, that it is in general adapted to the audience: the English have been ever remarked for being fond of loud music. Scaliger, as early as the time of Queen Elizabeth, gives that peculiarity among the features of their national character. Handel seems to have studied his audience perfectly: he knew that an English ear found less pleasure in the sound of a violin, than in the glorious notes of a drum.

IT has been objected by foreigners, that modern English music labours throughout under the absurdity of mistaken expression. For instance: when it would express any thing very high, the notes are raised high; if it would express the wonders of the deep, the word *deep* is taken down to the lowest note of the Diapason. Whereas, say they, depth and height have no resemblance whatever, but in name, to the different tones of music. In the same manner, joy, sorrow, and almost all the passions, are absurdly expressed, so that no passion is really excited but that of mirth, while music thus forgets its dignity by descending to imitation.

IT has been objected by foreigners to modern English music, that the concert pitch has been injudiciously altered. There is, say they, a certain stretch, at which all strings give their finest tones: that, in general, is the pitch which the other nations of Europe have found by experi-

experience to be their concert tone. In the colder climates, this pitch, if it be altered at all, should be let down; for sounds strike brisker in a cold air than in a warm, in frost, for instance, than in the sultry heats of autumn. A humid air also braces the string, and only adds to the tension of strings already raised above their tonic pitch.

To all these objections I can only answer, that, whatever be our defects in this way, modern Italian music, (for the French need not be mentioned, as some will scarce allow that they have any) modern Italian music, I say, is still more defective than ours. Whatever variety of expression ours may want from too much harmony, theirs actually wants from a deficiency of genius. I have heard a judicious friend observe, that he thought all the modern Italian cantata's but a repetition of the same tune. In fact, though they at present aim so much at simplicity, contrary to what is

usually imagined upon this subject, I have heard a finger throw more song into his voluntary close, than the composer had given him in his part. But in proportion as the composers are steril, their performers are compelled to be wild, and to make up in tawdry ornament what the piece wants in solidity. Music, notwithstanding, must be owned to have been indebted for many improvements to some later composers. Alberti is graceful, Tartini delicate, Rameau, though a Frenchman, often sublime; Handel's music is well adapted; but, after all, Correlli is still inimitable.

THEY who would desire a thorough knowledge of the mathematical principles, upon which the science of musical composition is founded, cannot have a better or more accurate guide than Smith's Treatise of Harmonics. They who would desire to consider the science in a more practical light, may consult a work some time since published by
Tartini,

Tartini, at Florence, entitled, *Trattato della Musica*, in which he considers the science both as a musician and a philosopher. Nor should I pass over the endeavours of Mr. Rameau upon this subject, in which he has attempted to give what he calls a new scale, consisting of eleven notes, each divided from the other by more exact proportions than in the present scale. This attempt, however, is not new. In fact, it is no more than the ancient scale, proposed near two thousand years ago by Aristoxenus. A new scale would be, at present, the same thing as to introduce among mankind, an universal language: both might be more commodious and more rational. However, men are better pleased with travelling in an old road that they know, though longer, than in finding out an unknown but shorter path, that may at best but conduct them to the same end, which the other did before.

C H A P. X.

Of Sound in general.

IF we were to examine all nature for a place proper for augmenting and echoing sounds with most force, and with greatest exactness, we should find the human ear to be best formed for these purposes. By its admirable contrivance it repeats sounds of all kinds, admits the greatest quantity into the smallest space, and echoes each back without confusion. Within the skull there is a large bony canal, that has one end opening into the ear, and the other running backwards with several turnings, somewhat resembling the internal windings of a common snail-shell. This labyrinth is lined within by a very fine skin, which is but an expansion of the nerves that serve for hearing, and which, uniting together towards the bottom, carry

carry the sounds directly to the brain. But before the sound can come to the labyrinth, it must necessarily strike against a thin skin, which is stretched, like the parchment of a drum, across a passage that leads from the outward ear into the mouth. This membrane or skin is called the drum of the ear, and, as in a common drum, there is a contrivance that seems calculated to brace or relax it at pleasure. About the use of this drum modern physiologists are divided. The common opinion is, that all sounds must first strike against this, and make its parts vibrate like a beaten drum, and that this vibration is communicated to the internal labyrinth, whose tremors correspond, and thus the sound is carried to the brain. They go on also to affirm, that when the drum of the ear is either too much relaxed, or totally destroyed, there can be no tremors of sound conveyed to the labyrinth, and that therefore the person must become deaf. This doctrine, however, is contradicted
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by others, who affirm, that persons hear perfectly well who have been totally deprived of this ear-drum; that others drive tobacco smoke, which they take in at their mouths, through both ears, and as in its passage it must necessarily be strained through the drum of the ear, (for there is no other way by which it can pass) they are apt to think that this membrane, which admits so gross a fluid, cannot be the proper instrument for hearing. Besides all this, they affirm that birds, whose hearing is very exquisite, are deprived of this apparatus, and therefore so may we, and yet still continue to hear. These objections are strong. The latest and most probable opinion therefore is, that the drum of the ear is not so much designed to render us capable of hearing sounds, (for we can hear without it) but to make us capable of exactly distinguishing them. To render us sensible of the difference between deep and shrill tones, or, as they are otherwise called, between sounds that

are grave, and such as are acute. For the reception of a shrill tone the drum is braced tightly, and therefore vibrates with the swiftest and shortest tremblings; in receiving the grave tones, it is braced more loosely, its tremblings therefore are free, wide, and open.

As a confirmation of this opinion, it is obvious, that those who have the drum of the ear any way inflamed or disordered, can bear to hear deep or grave sounds; but the shrill and acute give them inexpressible pain. In order to prepare for the shrill sound, the drum, as was said, must be braced up tight, and this bracing will necessarily be as painful as it would be to stretch out a finger straight that was contracted by an inflammation. However this be, the contrivance for the increase of sound in the ear is allowed to be admirable by all. Human ingenuity can make a machine, which may imitate vision exactly; but nothing that the art of man can form is
found

found to increase sounds so much in so small a compass as the human ear.

MOST sounds, we all know, are conveyed to us on the bosom of the air. In whatever manner they either float upon it, or are propelled forward in it, certain it is, that without the vehicle of this or some other fluid, we should have no sounds at all. Let the air be exhausted from a receiver, and a bell shall emit no sound when rung in the void; for, as the air continues to grow less dense, the sound dies away in proportion, so that at last its strongest vibrations are almost totally silent.

THUS air is a vehicle for sound. However, we must not with some philosophers assert, that it is the only vehicle; that if there were no air, we should have no sounds whatsoever: for it is found by trial, that sounds are conveyed through water almost with the same facility with which they move through air: a bell rung in water returns a tone
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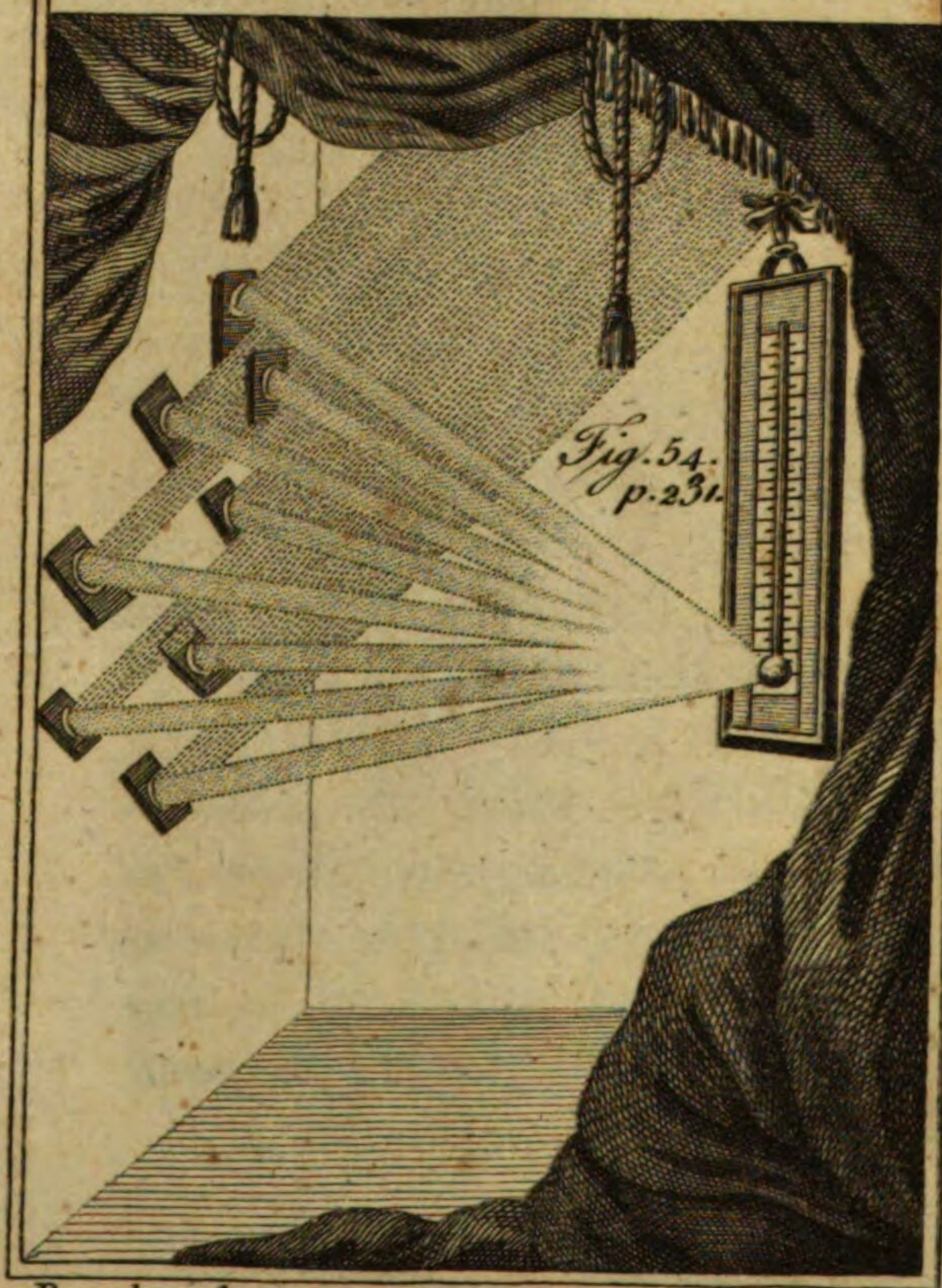
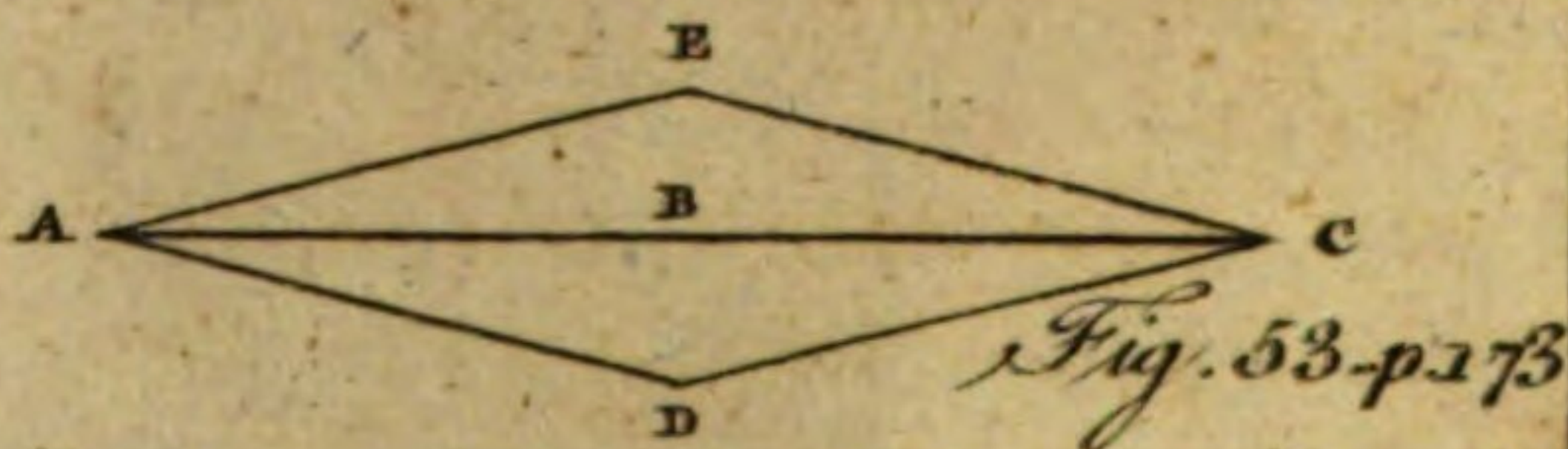
as distinct as if rung in our aerial atmosphere. This was observed by Derham, who also remarked, that the tone came a quarter deeper. Natural historians assure us also, that fishes have a strong perception of sounds, even at the bottom of deep rivers. From hence, therefore, we may, I think, reasonably infer, that it is not very material in the propagation of sounds, whether the fluid which conveys them be elastic or otherwise. Water, which of all substances that we know, has the least elasticity, yet serves to carry them forward; and if we make allowance for the difference of its density, perhaps the sounds move in it with a proportional rapidity, to what they are found to do in the elastic fluid of air. It may be said, indeed, that the water conveys sounds not of itself, but because mixed with a quantity of air, which is not totally deprived of its elasticity; that the sound is carried forward by the vibrations of this. To this way of reasoning we

we answer nothing : it may serve to fortify an hypothesis well enough, but it will never carry conviction with it.

ONE thing however is certain, that whether the fluid which conveys the note be elastic or non-elastic, whatever sound we hear is produced by a stroke, which the sounding body makes against the fluid, whether air or water. The fluid being struck upon, carries the impression forward to the ear, and there produces its sensation. Philosophers are so far agreed, that they all allow that sound is nothing more than the impression made by an elastic body upon the air or water, and this impression carried along by either fluid to the organ of hearing. But the manner in which this conveyance is made is still disputed : Whether the sound is diffused into the air, in circle beyond circle, like the waves of water, when we disturb the smoothness of its surface by dropping in a stone, or whether it travels along, like rays

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Vol II

*Proud sculp.*

rays diffused from a center, somewhat in the swift manner that electricity runs along a rod of iron; these are the questions which at present divide the learned, and are likely to continue to divide them.

NEWTON was of the first opinion. He has explained the progression of sound by an undulatory, or rather a vermicular motion in the parts of the air. If we have an exact idea of the crawling of some insects, we shall have a tolerable notion of the progression of sound upon this hypothesis. The insect, for instance, in its motion first carries its contractions from the hinder part, in order to throw its fore part to the proper distance, then it carries its contractions from the fore part to the hinder, to bring that forward. Something similar to this is the motion of the air when struck upon by a sounding body. To be a little more precise, suppose ABC, (see fig. 53.) the string of an harpstring screwed to a proper pitch, and drawn

drawn out of the right line by the finger at B. We formerly said, that such a string would, if let go, vibrate to E, and from E to D, and back again. We observed, that it would continue thus to vibrate like a pendulum for ever, if not externally resisted, and, like a pendulum, all its little vibrations would be performed in equal times, the last and the first being equally long in performing. We shewed also that, like a pendulum, its greatest swiftness would always be when it arrived at E, the middle part of its motion. Now then, if this string be supposed to fly from the finger at B, it is obvious, that whatever be its own motion, such also will be the motion of the parts of air that fly before it. Its motion, as is obvious, is first uniformly accelerated forward from B to E, then retarded as it goes from E to D, accelerated back again as it returns from D to E, and retarded from E to B. This motion being therefore sent in succession through a range of elastic air, it
must

must happen, that the parts of one range of air must be sent forward with accelerated motion, and then with a retarded motion. This accelerated motion reaching the remotest end of the first range will be communicated to a second range, while the nearest parts of the first range being retarded in their motion, and falling back with the recession of the string, retire first with an accelerated, then with a retarded motion, and the remotest parts will soon follow. In the mean time, while the parts of the first range are thus falling back, the parts of the second range are going forward with an accelerated motion. Thus there will be an alternate condensation and relaxation of the air, during the time of one vibration; and as the air going forward strikes any opposing body with greater force than upon retiring, so each of these accelerated progressions have been called by Newton a pulse of sound.

THUS will the air be driven forward in the direction of the string. But now we must observe, that these pulses will move every way; for all motion impressed upon fluids in any direction whatsoever, operates all around in a sphere: so that sounds will be driven in all directions, backwards, forwards, upwards, downwards, and on every side. They will go on succeeding each other, one without side the other, like circles in disturbed water; or rather, they will lie one without the other, in concentric shells, shell above shell, as we see in the coats of an onion.

ALL who have remarked the tone of a bell, while its sounds are decaying away, must have an idea of the pulses of sound, which, according to Newton, are formed by the air's alternate progression and recession. And it must be observed, that as each of these pulses are formed by a single vibration of the string,

string, they must be equal to each other; for the vibrations of the string are known to be so.

AGAIN, as to the velocity with which sounds travel, this Newton determines, by the most difficult calculation that can be imagined, to be in proportion to the thickness of the parts of the air, and the distance of these parts from each other. From hence he goes on to prove, that each little part moves backward and forward like a pendulum; and from thence he proceeds to demonstrate, that if the atmosphere were of the same density every where as at the surface of the earth, in such a case, a pendulum that reached from its highest surface down to the surface of the earth, would by its vibrations discover to us the proportion of the velocity with which sounds travel. The velocity with which each pulse would move, he shews, would be as much greater than the velocity of such a pendulum swinging with one complete vibration,

bration, as the circumference of a circle is greater than the diameter. From hence he calculates, that the motion of sound would be nine hundred and seventy-nine feet in one second. But this not being consonant to experience, he takes in another consideration, which destroys entirely the rigour of his former demonstration, namely, vapours in the air, and then finds the motion of sound to be one thousand one hundred and forty-two in one second, or near thirteen miles in a minute: a proportion which experience had established nearly before.

THUS much will serve to give an obscure idea of a most obscure theory: a theory which has met with numbers of opposers; some more forward, condemning what they thought they knew, but did not really understand; others more prudent, condemning the whole doctrine, not as false, but because obscure. Even John Bernouilli, Newton's greatest
disciple,

disciple, modestly owns that he did not pretend to understand this part of Newton's Principia. He attempted therefore to give a more perspicuous demonstration of his own, that might confirm and illustrate the Newtonian theory. The subject seemed to reject elucidation: his theory is obviously wrong, as D'Alembert has proved in his Theory of Fluids. Euler, therefore, rejecting the Newtonian doctrine entirely, has attempted to establish another; but as he has hitherto only given the result of his calculations, without the progressive proofs that confirm his opinion, the learned continue in suspense as to the merit of his work.

VARIOUS have been the objections that have been made to the Newtonian system of sounds. First, it is urged, that if the first pulse of sound be driven by that which immediately follows, and that by the succeeding, and so on, it must then happen, that the more numerous the pulses, the farther will the sound be

driven ; so that a string which vibrates the longest will be heard at the greatest distance, which is contrary to known experience. Again, it is urged, that this theory can only agree with the motion of sound in an elastic fluid, whereas sounds are known to move forward through water that is not elastic : to explain their progress therefore through water, a second theory must be formed : so that two theories must be made to explain a similar effect, which is contrary to the simplicity of true philosophy, for it is contrary to the simplicity of nature. It is still farther urged, that this slow vermicular motion but ill represents the velocity with which sounds travel, as we know by experience, that it is almost thirteen miles in a minute. In short, it is urged, that such undulations as have been described, when coming from several sonorous bodies at once, would cross, obstruct, and confound each other ; so that, if they were conveyed to the ear by this means, we should hear nothing but
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a medley of discord, and broken articulations. But this is equally with the rest contradictory to experience, since we hear the fullest concert, not only without confusion, but with the highest pleasure. These objections, whether well founded or not, have given rise to another theory. The reader must judge for himself, which of the two he will prefer : *non nostrum est tantas componere lites.*

EVERY sound may be considered as driven off from the founding body in straight lines, and impressed upon the air in one direction only ; but whatever impression is made upon a fluid in one direction, is diffused upon its surface into all directions : so that the sound first driven directly forward soon fills up a wide sphere, and is heard on every side. Thus, as it is impressed, it instantaneously travels forward with a very swift motion, resembling the velocity with which we know electricity flies from one end of a line to another.

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Now, as to the pulses, or open shakes as the musicians express it, which a sounding body is known to make, a little reflection may serve to shew, that each pulse is itself a distinct and perfect sound, and that the interval between every two pulses is profoundly silent. Continuity of sound from the same body is only a deception of the hearing; for as each distinct sound succeeds at very small intervals, the organ has not time to transmit its images with equal swiftness to the mind, and the interval is thus lost to sense: just as in seeing a flaming torch, if flared round in a circle, it appears as a ring of fire. In this manner a beaten drum, at some small distance, presents us with the idea of continuing sound. When children run with their sticks along a rail, a continuing sound is thus represented, though it need scarce be observed, that the strokes against each rail is perfectly distinct and insulated.

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ACCORDING to this theory, therefore, the pulses are nothing more than distinct sounds repeated by the same body, the first stroke or vibration being ever the loudest, and travelling farther than those that follow; while each succeeding vibration gives a new sound, but with diminished force, till at last the pulses decay away totally, as the force decays that gives them existence.

ALL bodies whatsoever that are struck, return more or less a sound; but some wanting elasticity, give back a repetition of the sound: the noise is at once begotten and dies; while other bodies, however, there are, which being more elastic, and whose parts are capable of vibration, give back a sound, and repeat the same several times successively. These last are said to have a tone; the others are not allowed to have any.

THIS tone of the elastic string or bell is notwithstanding nothing more than a
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similar sound to what the former bodies produced, but with the difference of being many times repeated, while their note is but single. So that, if we would give the former bodies a tone, it will be necessary to make them repeat their sound, by repeating our blows swiftly upon them. This will effectually give them a tone, and even an unmusical instrument has often had a fine effect by its tone in our concerts.

LET us now go on then to suppose, that by swift and equably continued strokes we give any non-elastic body its tone, it is very obvious, that no alterations will be made in this tone by the quickness of the strokes, though repeated never so fast. These will only render the tone more equal and continuous, but make no alteration in the tone it gives. On the contrary, if we make an alteration in the force of each blow, a different tone will then undoubtedly be excited. The difference will be small, I must confess,

for the tones of these inflexible bodies are capable but of small variation; however, there will certainly be a difference. The table on which I write, for instance, will return a different sound when I strike it with a club, from what it did when I only struck it with a switch. Thus non-elastic bodies return a difference of tone, not in proportion to the swiftness with which their sound is repeated, but in proportion to the greatness of the blow which produced it; for in two equal non-elastic bodies, that body produced the deepest tone that was struck by the greatest blow.

WE now then come to a critical question, What is it that produces the difference of tone in two elastic sounding bells or strings? Or what makes one deep and the other shrill? This question has always been hitherto answered by saying, that the depth or height of the note proceeded from the slowness and swiftness of the times of the vibrations. The
slowest

slowest vibrations, it has been said, are qualified for producing the deepest tones, while the swiftest vibrations produce the highest tones. In this case an effect has been given for a cause. It is in fact the force with which the sounding string strikes the air when struck upon, that makes the true distinction in the tones of sounds. It is this force, with greater or less impressions, resembling the greater or less force of the blows upon a non-elastic body, which produces correspondent affections of sound. The greatest forces produce the deepest sounds: the high notes are the effect of small efforts. In the same manner a bell, wide at the mouth, gives a grave sound; but if it be very massy withal, that will render it still graver; but if massy, wide, and long or high, that will make the tone deepest of all.

Thus then will elastic bodies give the deepest sound, in proportion to the force with which they strike the air; but if
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we should attempt to increase their force by giving them a stronger blow, this will be in vain: they will still return the same tone; for such is their formation, that they are sonorous only, because they are elastic, and the force of this elasticity is not increased by our strength, as the greatness of a pendulum's vibration will not be increased by falling from a greater height.

THUS far of the lengths of cords; now as to the frequency with which they vibrate the deepest tones, it has been found, from the nature of elastic strings, that the longest strings have the widest vibrations, and consequently go backward and forward slowest; while, on the contrary, the shortest strings vibrate the quickest, or come and go in the shortest intervals. From hence those who have treated of sounds have asserted, as was said before, that the tone of the string depended upon the length or the shortness of the vibrations. This, however, is not the case.

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One and the same string, when struck, must always, like the same pendulum, return precisely similar vibrations; but it is well known, that one and the same string, when struck upon, does not always return precisely the same tone: so that in this case the vibrations follow one rule, and the tone another. The vibrations must be invariably the same in the same string, which does not return the same tone invariably, as is well known to musicians in general. In the violin, for instance, they can easily alter the tone of the string an octave or eight notes higher, by a softer method of drawing the bow; and some are known thus to bring out the most charming airs imaginable. These peculiar tones are by the English fiddlers called Flute Notes, if I mistake not. The only reason that can be assigned for the same string thus returning different tones, must certainly be the different force of its strokes upon the air. In one case, it has double the tone of the other, because upon the soft touches
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of the bow, only half its elasticity is put into vibration.

THIS being understood, we shall be able clearly to account for many things relating to sounds that have hitherto been inexplicable. Thus, for instance, if it be asked, When two strings are stretched together of equal lengths, tension, and thickness, how does it happen, that one of them being struck, and made to vibrate throughout, the other shall vibrate throughout also? The answer is obvious: the force that the string struck receives is communicated to the air, and the air communicates the same to the similar string, which therefore receives all the force of the former, and the force being equal, the vibrations must be so too. Again put the question, If one string be but half the length of the other, and be struck, how will the vibrations be? The answer is, the longest string will receive all the force of the string half as long as itself, and therefore it will vibrate in
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proportion, that is, through half its length. In the same manner, if the longest string were three times as long as the other, it would only vibrate in a third of its length : or if four times, in a fourth of its length. In short, whatever force the smaller string impresses upon the air, the air will impress a similar force upon the longer string, and partially excite its vibrations.

FROM hence also we may account for the cause of those charming, melancholy gradations of sound in the Eolian lyre, a modern instrument, invented by Mr. Oswald. The Eolian lyre is easily made, being nothing more than a long narrow box of thin deal, about a yard long, and four inches wide, with an hole on one side. On this side are seven strings of very fine gut, stretched over bridges at each end, like the bridge of a fiddle, and screwed up or relaxed with screw pins. The strings are all tuned to one and the same note, and the instrument is placed
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in some current of air, where the wind can brush over its strings with freedom. A window with the sash just raised, to give the air admission, will answer this purpose exactly. Now when the entering air blows upon these strings with different degrees of force, there will be excited different tones of sound; sometimes the blast brings out all the tones in full concert; sometimes it sinks them to the softest murmurs; it feels for every tone, and by its gradations of strength solicits those gradations of sound, which art has taken different methods to produce.

We come now, in the last place, to consider the loudness and the lowness, or as musicians speak, the strength and softness of sounds. In vibrating elastic strings, the loudness of the tone is in proportion to the deepness of the note; that is, in two strings, all things in other circumstances alike, the deepest tone will be loudest. In musical instruments,

upon a different principle, as in the violin, it is otherwise; the tones are made in such instruments, by a number of small vibrations crowded into one stroke. The refined bow, for instance, being drawn along a string, its roughnesses catch the string at very small intervals, and excite its vibrations. In this instrument, therefore, to excite loud tones, the bow must be drawn quick, and this will produce the greatest number of vibrations. But it must be observed, that the more quick the bow passes over the string, the less apt will the roughness of its surface be to touch the string at every instant; to remedy this, therefore, the bow must be pressed the harder as it is drawn quicker, and thus its fullest sound will be brought from the instrument. If the swiftness of the vibrations in an instrument thus rubbed upon, exceed the force of the deeper sound in another, then the swift vibrations will be heard at a greater distance, and as much farther off, as the swiftness

swiftness in them exceeds the force in the other.

BUT one thing more remains. It may be objected to this theory, that if the tone of a string was caused by the force of its stroke, then those parts of the air that were nearest the sounding body would be impressed with the greatest force, and would therefore give the greatest or deepest tone; while, as the sound went off to a greater distance, and the force became consequently less, the tone would become less also; or, in other words, grow higher and higher: but this, continue the objectors, is known, by experience, to be otherwise. To this it might be answered, that the force once impressed continues ever the same. But, in fact, I am apt to allow their objection, but to deny their conclusion. I am inclined to believe that the tone actually alters as it travels onward, becoming higher, as it recedes from the sounding body. I would offer the following rea-

sons for this opinion, rather as motives to excite farther search, than as decisions to satisfy curiosity. In hearing distant sounds, it is probable, we labour under the same continual deceptions which we do in seeing distant objects; the judgment in both is ever correcting the erroneous representation of the senses. A man, when seen at a mile's distance, appears actually but a few inches tall, yet the person who sees him, would be surprised, if told, that what he saw was an object no bigger than his finger. It may be the same with sounds; the tone may diminish by distance, and yet we may not be sensible of it without a nice comparison. It may be added, that as visual objects, when placed at a distance, fade from the sight, and assume the colour of the air as they remove; so sounds, to use the painter's word, may have their *keeping* in like manner, and thus by becoming indistinct and low.

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THAT we labour under a deception with regard to tones, and that they become higher as they come from a greater distance, may be inferred from musical composition. The greatest masters in this art, when they would imitate a distant echo, generally take the sounds an octave higher. A few years ago, a fellow exhibited in Westminster, the art of imitating sounds at any distance whatever. I remarked, that whenever he designed to imitate a voice coming from a great distance, he not only made the sound more low and indistinct, but raised the tone several pitches higher than that used in his nearer imitations. A few observations since made upon sounds, induce me to believe, that they become higher as they come from a distance more remote ; while, on the contrary, that they deepen, the more the vibrations approach the labyrinth of the ear. The following easy and common experiment I think will prove it. Take any thing whatever, capable of giving a

found; let it be a common poker, for instance; and tying on a garter at top, so as that both ends of the garter are left at liberty; these ends must be rolled round the first finger of each hand, and then with these fingers stopping the ears close, strike the poker, thus suspended, against any body whatsoever. The depth of the tone which this new musical instrument returns will be amazing. The deepest and largest bell will not equal it. Whence is this, unless from the close approach of the founding body, whose vibrations are immediately communicated to the internal parts of the ear. I am sensible that many objections may be made to this last opinion; succeeding experience must, however, determine whether it be just or not: but such as make them must be particularly careful, not to let their former experience correct their immediate sensations. This alteration of tone, with distance, however, must diminish but by great intervals. The first part of this theory appears to
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me very probable, whatever befalls the latter part of it. Some of the outlines are taken from some hints dropped by Mr. Buffon.

HOWEVER it may be with regard to the theories of sound, experience has taught us, that it travels at about the rate of 1142 feet in a second, or near thirteen miles in a minute. The method of calculating its progress is easily made known. When a gun is discharged at a distance, we see the fire long before we hear the sound. If then we know the distance of the place, and know the time of the interval between our first seeing the fire and then hearing the report, this will shew us exactly the time the sound has been travelling to us. For instance, if the gun is discharged a mile off, the moment the flash is seen, I take a watch and count the seconds till I hear the sound; the number of seconds is the time the sound has been travelling a mile.

DERHAM has gone yet farther, and proved by experience, that all sounds whatever travel at the same rate. The sound of a gun, and the striking of a hammer, are equally swift in their motions; the softest whisper flies as swiftly, as far as it goes, as the loudest thunder.

As sound is communicated from a single point, in every direction, it must, of consequence, diminish in strength the farther it goes. All bodies sent out directly in rays from a center, meet greater resistances, as the squares of their distances become greater; and therefore the progress of sounds will be resisted in proportion, as their distances, by being squared, increase.

THIS, however, must not be considered as a constant rule; for when a sound travels against the wind, it takes a longer time than when it flies before it. Of consequence it goes faster one way than the other, and thus, as it is no longer

longer diffused in a sphere, the law of its progress forward must also be altered. Ulloa thinks that the same sound which, against a strong wind, travels nine miles and a half, would, if it went with the wind in the same time, travel ten miles and a half, that is a whole mile farther.

To drive the human voice to the greatest distance, we are obliged to make use of art. The instrument called the speaking trumpet is well known at land ; but it is indispensably necessary at sea. The voice reflected from the sides of this tube, which is made pretty much in the figure of an huntsman's straight horn, is increased at its mouth, and thus, as it is said, strikes the air with greater force. There are very different opinions, both with respect to the manner in which the speaking trumpet increases sound, and also with regard to the best figure of such an instrument ; the logarithmic curve has been adopted by some, and the parabolic curve by others ; it is for geometri-
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cians to dispute ; artists usually chuse a figure peculiar to themselves.

A subject not less disputed than the former, and still less understood, is the cause and nature of an echo. It is said, in general terms, that an echo is a reflection of sound, striking against some object, as an image is reflected in a glass. If this, however, were the case, all bodies with a smooth surface would be capable of reflecting sounds, which we know, by experience, they are not. That the sound is reflected none can deny, the great difficulty lies in determining what are the proper qualities in a body for thus reflecting sounds. Were this precisely known, we should then be able to make an echo at pleasure ; but some have found, to their cost, that such an attempt is impracticable ; whatever arts they have tried to bring the coy nymph to their gardens or pleasure-houses, have proved ineffectual ; a poet would say, that she flies the palaces
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of the great, content with solitude and privacy.

IT is in general known, that caverns, grottoes, mountains, and ruined buildings return this image of sound. Image we may call it, for in every respect it resembles the image of a visible object reflected from a polished surface. Our figures are often represented in a mirrour, without seeing them ourselves, while those standing on one side are alone sensible of the reflection. To be capable of seeing the reflected image of ourselves, we must be directly in a line with the image. Just so is it in an echo; we must stand in the line in which the sound is reflected, or the repetition will be lost to us, while it may, at the same time, be distinctly heard by others who stand at a small distance to one side of us. I remember a very extraordinary echo, at a ruined fortress near Louvain, in Flanders. If a person sung, he only heard his own voice, without any repetition, on the
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contrary, those who stood at some distance, heard the echo but not the voice; but then they heard it with surprising variations, sometimes louder, sometimes softer, now more near, then more distant. There is an account in the memoirs of the French academy, of a similar echo near Rouen. The building which returns it is a semicircular courtyard; yet all buildings of the same form do not produce the same effects. We find some music halls excellently adapted for sounds, while others, built upon the same plan, in a different place, are found to mix the tones, instead of enlarging them, in a very disagreeable manner.

As we know the distance of places by the length of time a sound takes to travel from them, so we may judge of the distance of an echo, by the length of the interval between our voice and its repetition. The most deliberate echoes,

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as they are called, are ever the most distant ; while on the contrary, those that are very near, return their sounds so very quick as to have the interval almost imperceptible ; when this is the case, and the echo is so very near, the voice is said to be increased and not echoed ; however, in fact, the increase is only made by the swiftly pursuing repetition. Our theatres and concert rooms are best fitted for music or speaking, when they enlarge the sound to the greatest pitch, at the smallest interval : for a repetition which does not begin the word till the speaker has finished it, throws all the sounds into confusion. Thus the theatre at the Haymarket, enlarges the sound very much ; but then, at a long interval, after the singer or speaker. The theatre at Drury-lane, before it was altered, enlarged the sound but in a small degree ; but then the repetition was extremely quick in its pursuit ; and the sounds, when heard, were therefore heard distinctly. Dergolise, the

great musical composer, used to say, that an echo was the best school-mistress; for let a man's own music be never so good, by playing to an echo she would teach him to improve it.

C H A P. XI.

*Of some anomalous Properties of the Air,
which have not been yet accounted
for.*

BESIDE these properties of the air, there are several others the causes of which are more obscure, or to speak more ingenuously, the causes of which we are not able to assign with so strong an appearance of truth. Boyle has given us a chapter expressly upon this subject; where like a true philosopher he confesses the limits of his own powers, and where he cannot find the true causes, refuses to give conjectural ones. The vital principle of the air is one of its properties which cannot be accounted for, and which foil human sagacity: that principle which it is possessed of in feeding flame, is also equally inscrutable; it is driven off by heat, yet still
8 more

more strange, heat cannot be continued without it.

The power it has of whitening some bodies and tanning others, is a property we may admire, but cannot account for. We are at a loss also to account for the aptitude of the air, in keeping heterogeneous bodies supported on its bosom, while the heavier fluids of the same region and the same place are quite free from those substances. Thus it is often found, that the air of some countries is extremely unhealthful and noxious, while the waters of the same place are admired for their salubrity. We have a short memoir of one of the members of the Academy of Sciences in Paris to this purpose; "A mason working by the side of a deep well near the city of Rennes, happening to let his hammer fall, one of the labourers who attended him, went down, but was suffocated before he reached the bottom: the same thing befel a second, who went down to draw
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up the body ; a third also underwent the same fate : a fourth, almost drunk, was let down, but with positive assurances to be drawn up the moment he gave the signal ; this he quickly gave, but was drawn up senseless, and died in three days after. The most extraordinary circumstance of the relation is, that the water of this well had long been used by the neighbourhood without any noxious effects whatsoever.

ANOTHER of the air's inscrutable qualities is, that if kept for some time inclosed in a vessel without any communication with the external atmosphere, it becomes deadly and pestilential in the highest degree ; all animals that are obliged to respire in it instantly die. We have another account of the pestilential effects of close air, related in the same work : “ A baker of Chartres had a cellar under his house, to which there was a descent by a staircase of thirty-six steps. Thither his son, a strong young

man, went to carry down a sack of bran, but while he was on the steps the candle was extinguished. Unconcerned at this, which he regarded as an accident, he went back, lighted his candle, and again returned; but as soon as he came to the lowest step he cried out, that he was unable—death interrupted the exclamation. His brother, a youth as remarkable for strength as the former, instantly ran down to his assistance; but soon cried out that he was dying, and his cries ceased a few moments after. His wife went to his rescue, a servant maid followed her, they were all suffocated. This accident terrified the whole village, and the inhabitants fled from the house with precipitation. At length one more resolute than the rest, being persuaded that they were not yet dead, went down to assist them, but he was soon a sharer in their fate. Not daunted at this, the next day a friend of the baker's was let down into the cellar by a cord; upon his crying out they attempted

tempted to draw him up again, but the cord breaking, he fell into the cellar and was suffocated instantly."

THE blood vessels of the brain upon dissection appeared distended, and the bowels inflamed. Upon throwing in a large quantity of water into the cellar these noxious effects were dispersed, and a candle having been let down was drawn up without being put out, a certain indication of the melioration of the air.

ANOTHER property of the air, which has not yet been accounted for, is, that globular figure its parts assume, when the air, by means of the pump, or by fire, is forced out of the substances into which it has insinuated. The bubbles in this case are always round; and though the bubble happens to swell to a thousand times its former dimensions, yet its globular figure still remains. Can the parts of air of which these globules are

composed be round themselves? Or will any number of globes by being in contact one with the other, compose a figure that is round?

BUT of all the inscrutable properties of the air, that by which it conveys sounds from one place to another, is at present esteemed the most obscure: in the last age, when a philosopher would blush if he could not be thought to assign a ready cause for every effect in nature, we then had theories of the progression of sound through an elastic fluid, and such were generally embraced by the learned. These theories, it must be owned, though they added nothing to a scholar's former fund of learning, yet served to conceal the bounds of what he knew; for an obscure answer will always satisfy the demands of inquisitive ignorance, and create its esteem: however, the doctrine of sounds is now acknowledged the most obscure part of natural philosophy. The reason may be easily

easily assigned. Newton attempted it without success; and succeeding philosophers have not had talents equal to the elucidation of what he left obscure. The two minims, Le Sueur and Jacquier, who commented upon his *Principia*, have proved the Newtonian hypothesis, relating to the motion of the particles of an elastic medium, to be fallacious, and have proposed other methods for restoring the Newtonian doctrine of sound; but neither have their explanations carried universal conviction; a presumptive proof of their weakness or obscurity.

color against Newton's attempt to
show that light is made of particles
and that the rays of light are equal to the
disturbance of what he calls the ether.
The two minutes in which he has
spent, who has examined them, has
seen that he has proved the Newtonian hy-
pothesis relating to the motion of the
particles of an elastic medium to be fal-
lacious, and have proposed other methods
for refuting the Newtonian doctrine of
light; but neither have they explained
them, carried out, or shown a
presumptive proof of their weakness or
obscure.

A
S U R V E Y
O F
EXPERIMENTAL
PHILOSOPHY.

B O O K III.

CHAPTER I.

OF FIRE.

Ignis ubique latet, naturam amplectitur omnem,
Cuncta parit, renovat, dividit, urit, alit.

THESE are the properties of Fire
as enumerated by a modern wit;
and nothing can be at once more full and
more concise. All things contain Fire, says

he, in some degree; it produces, it renews, divides, consumes, or nourishes every part of Nature: every person's experience must inform him of the obvious properties of Fire; and in fact, philosophers more readily prove its existence, than give its definition.

WHAT is Fire? This is a question which has divided the greatest men, as well among the ancients as moderns: of the latter, Boerhaave, Homberg, and Lemery, suppose fire to be a body actually existing, like air, water, or any other fluid, and diffused through all nature. It is to be found, say they, in all places and in all things, only wanting to be collected into a narrow compass, in order to become manifest to the senses. They say, that, upon uniting with other bodies, it not only increases their bulk, but their weight also. That it sometimes is collected in such a manner, that some of its properties only appear, as when it shines without burning: at other times different

rent properties are collected, and it burns without shining, as in metals heated to a certain pitch.

To these chymical philosophers are opposed no less names than Bacon, Boyle, and Newton: these deny that fire is by any means itself a body, but only arises from the attrition or rubbing of bodies one against the other. Charcoal ignited, say they, what is it but wood made red and burning? A bar of iron hissing from the forge, what is it but iron still? In short, say they, wherever a violent attrition or intestine motion of the parts can be excited between bodies, fire will be the necessary result; such bodies will sometimes cast forth flame, and flame is itself nothing more than parts excessively small, put violently into motion.

MODERN philosophers in general incline to the opinion of Boerhaave, and concur with the ancients in affirming,
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that fire is an element of a peculiar kind and an inscrutable nature, with properties peculiar to itself, every where appearing, but no where certainly known. Let us leave therefore the nature of this element to those who love disputation, and give the most obvious properties of fire, but without attempting in the least to investigate their cause.

THE most constant property of fire is its heat: heat is ever found to increase the bulk of all bodies before it begins to consume them. When heat is applied to any substance, to iron for instance, in a moderate degree it swells; the same heat increased still, increases all its dimensions. As long as the heat or fire is continued, the dilatation increases, and the more ardent the one becomes, the more bulky still will be the other. The dilatation, however, of the substance has its bounds, nor can it be infinitely increased. When the fire is first applied, the dilatation begins slowly; it then accelerates till it comes

comes to a certain pitch, then it goes on slowly again; but at last, though the fire be never so ardent, or continued never so long, the dilatation is at a stand. If we would desire to know exactly in what proportion bodies of different hardness or different weights dilate; this neither theory nor experience can resolve. Some very hard bodies dilate more than others less hard; but then some bodies harder still, dilate less than either. Tin dilates sooner than the softer body, lead; iron, harder than tin, dilates less than either of them.

OF all fluids which are dilated by heat, air is the most easily expanded: next to that the chymical æther, then spirit of wine, then the oil called petroleum, then oil of turpentine, rape oil, distilled vinegar, fresh water, salt water, spirit of vitriol, spirit of nitre, and quicksilver,

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IN order to measure this expansion of bodies, as well by fire as by a more moderate heat, two instruments have been contrived; namely, the pyrometer, and the thermometer: the pyrometer serves to shew the degrees of heat in solid bodies, the thermometer in fluids; the pyrometer is usually nothing more than a rod of metal equally heated and so fixed, that as the heat increases, its minutest dilatations may be discovered by a nice adjusted scale. Several methods of making them have been proposed; all the methods are equally good, as the instrument at best can answer but few purposes of either speculation or utility.

THE thermometer is an instrument much more known, and infinitely more useful; it very precisely measures the degree of heat in all fluids, and consequently informs us of the temperature of the air. This instrument shews exactly when the weather is hot and when
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it is cold, which, whatever we may boast of our natural sensations, they but very imperfectly discover. A man, for instance, going into a warm apartment of a bagnio, finds the air of the room excessively warm; but after being for some time in the bath, which is still hotter, if he then comes out into the same apartment, though the air still continues the same, he shall think it excessively cold. The travellers who go up the Andes, which are the highest mountains in the world, often meet other travellers coming down, who have been in the province of Quito, which lies near its top. Their sensations are very different, as Ulloa informs us. The descending traveller, who has left the cold country above, is almost stifled with heat; the traveller, who ascends from the torrid regions below, freezes with cold; the one throws off his garment, and the other seizes it with haste to keep himself warm. As our natural feelings are thus incapable of distinguishing the real warmth of the
air,

air, or any other substances, the thermometer is called in, which answers the end with much greater precision. This instrument is nothing more than a fluid inclosed in a glass tube nicely marked, and as the fluid swells with heat, it fills more of the tube, and consequently rises higher ; on the contrary, as it contracts with cold, it sinks in the tube ; and thus rising or falling, measures the true temperature of the weather, or the degree of heat in any fluid into which it is immersed. The thermometer was first discovered by one Drebbel, a common Dutch peasant, who used it merely to direct him in his occupations of husbandry. Philosophers soon found the use of such an instrument, improved and converted it to purposes far beyond what the inventor had any idea of. The thermometer now used most frequently, is that of Fahrenheit's improvement. The fluid with which the bulb at the bottom is filled, is mercury ; upon the side of the tube are marked the divisions at which

which the fluid expands by different degrees of heat from freezing, which he calls the freezing point, up to the greatest heats fluid substances are capable of receiving. Thus when we say, human heat is ninety-eight degrees by Fahrenheit's thermometer, it means only this, that the heat of a man's body is ninety-eight of those degrees warmer than water when it begins to freeze. On the other hand, when we are told, that in Greenland the mercury sometimes stands seven degrees lower than 0 by Fahrenheit's thermometer, it only implies that the air is seven degrees colder than water when it begins to freeze. Several other kinds of thermometers have been made use of by different naturalists; the difference in any of them is not very material, it is only proper that they should hold to some one standard, otherwise when a philosopher tells us, that the air is at such a time thirty degrees of his thermometer, we can have no idea of its peculiar heat, unless

unless we have a draught of his peculiar instrument also. Newton's thermometer measured the degrees of heat with oil instead of mercury; perhaps such an instrument is more just, but it is by no means so portable as the former.

PHILOSOPHERS having thus agreed upon instruments that can precisely measure the degrees of heat and cold, can understand each other, when they talk of the different dilatations in bodies, with precision.

BUT heat does not only increase the bulk of bodies, but increases their weight also. A body weighed nicely before it is put into the fire, and then weighed again, will be found to be increased in weight very sensibly. It is remarkable enough, that lead when melted and reduced by heat to a red powder, receives a considerable addition to its weight from the operation of the fire, even after it is become cold again: a pound of lead
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by being thus reduced by heat, shall weigh several grains heavier than before.

IT is not however the property of fire always to heat or expand those bodies in which it resides, for we frequently see it emitting light while it is perfectly cold. Phosphorus, which shines in the dark, rotten wood, several kinds of fish, or flesh as it begins to putrefy, and several other substances, all emit a light sensibly. So that light and heat may be considered as two social qualities which are propagated from the same source, namely, from fire; but though usually together, yet by some unknown means are often found disunited.

HOT water cools sooner by being placed under the exhausted receiver of an air pump, while on the contrary iron cools sooner in the open air. Shining rotten wood loses all its light in the void, and never recovers it again; on the other hand, the glow-worm loses

its light, but soon recovers it again in the open air. If several bodies of different heats are all placed in the same close apartment, after a short time the heat will be equally diffused among them, and the thermometer will shew the degrees to be the same in all. Bodies heat by being exposed to the air, but never if their moisture be dried away. Hay when moist will take fire of itself, when dried it remains secure.

WOOD rubbed very swift with a circular motion takes fire. Several liquors poured one upon the other, though cold before, immediately take fire; such as any acid, a spirit of vitriol for instance, when mixed with any essential oil, as oil of cloves. A flint struck against a steel emits sparks of fire, the sulphur contained in the flint heating and melting the metal of the iron, and mixing with it and falling in small drops, which may be gathered upon paper, and attracted by the loadstone. But a property still more
extraor-

extraordinary than any hitherto mentioned is, that these sparks shall set fire to gunpowder, and the flame of a candle will not. In several mines in different parts of England, they are obliged to have very different kinds of light to carry on their work by. The flame of a candle in some mines would set their whole works on fire : they are therefore obliged to have a wheel with flints set round the circumference like the cogs of a mill wheel ; these flints continually striking a steel properly disposed give a light, which serves to guide the operations of the workmen. Yet though such a machine be requisite in some places, a single spark struck between flint and steel would instantly fire other mines where they work by the light of flame, and be more fatal than the explosion of tons of gunpowder : these are all properties of this element, for which we can assign no reason that impresses the smallest conviction.

THERE seem to be two sources of fire by which all nature is refreshed, assisted, and even animated; for philosophers now begin to allow, that animals may be produced from no other parent than heat alone. There are probably, I say, two sources of fire, the central, or that heat which is contained deep in the bowels of the earth, and the solar, or sun's heat. In digging mines or wells it is observed, that at a small distance below the surface of the earth, the air feels a little chill; somewhat deeper it is colder, and when the workmen have come precisely to that depth, beyond which the rays of the sun cannot penetrate, water is found to freeze: when they descend still more deep to about fifty feet below the surface, they then begin to perceive the place a little warmer and ice melts. The deeper they descend from this point, the more does the heat increase, until at length their breathing becomes difficult and their candles go out.

By

By this central heat many have explained earthquakes, the production of gems, minerals, and even the nutrition of vegetables. They who are most wedded to the system, regard this heat as a central sun, enlivening and refreshing nature beneath the surface of the earth, as the planetary sun does the external parts of the system. Boyle, however, ascribes the increase of heat at the lowest depths to vapours, which mixing with others of a different and opposite nature, produce heat and sometimes flame, as we see sulphur when kneaded into a paste with filings of iron frequently does.

THE sun, as we all experience, is the cause of heat, at the surface of the earth: whatever regions are struck by its rays most perpendicularly, feel the influence of its heat with greatest violence. For every object, placed directly beneath the rays, receive them in greatest quantity; and besides, every object that receives the perpendicular ray, will also

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receive

receive the reflected rays, which will not be the case, if they fall obliquely; a material consideration, though not usually taken notice of. This heat of the sun, which is so great at the surface of the earth, is much diminished as we ascend above it; so that the tops of mountains are generally extremely cold; and though some of them are internally fraught with fire, yet externally they are covered with snow. The mountain of Hecla, in Iceland, sometimes casts forth flames and earth melted like glass into a flaming torrent; this runs down its sides in rivers, while the collected snow drives before the current, and the whole makes the most hideous cataract in nature. The cause of mountains being thus more cold than the valley below, is obvious; the valley reflects all the rays of the sun, warms the air, and drives the rays back directly against the observer: the mountain reflects its rays in a smaller quantity; the air is thin, and will not admit of much warmth, and the

the observer is more out of the line of each reflected ray.

OF all bodies which reflect or throw back the rays of the sun, those which are smooth, well polished, and but little porous, do it most powerfully; while, on the contrary, soft, spongy, porous bodies, reflect back but a few rays in comparison, but, in a manner, suck them up and keep them within themselves. A looking glass will throw back the rays that fall upon it very powerfully, with light and warmth, while a pillow shall scarce reflect any rays whatsoever. Of all substances however, polished steel reflects the rays most, while, on the contrary, wool has the smallest power of reflection, transmitting the rays, and suffering them to pass through its substance in the greatest number. And for this reason, wool that thus imbibes the rays in such great quantities must necessarily be warmer than any other substance; though Reaumur, in hatching chickens

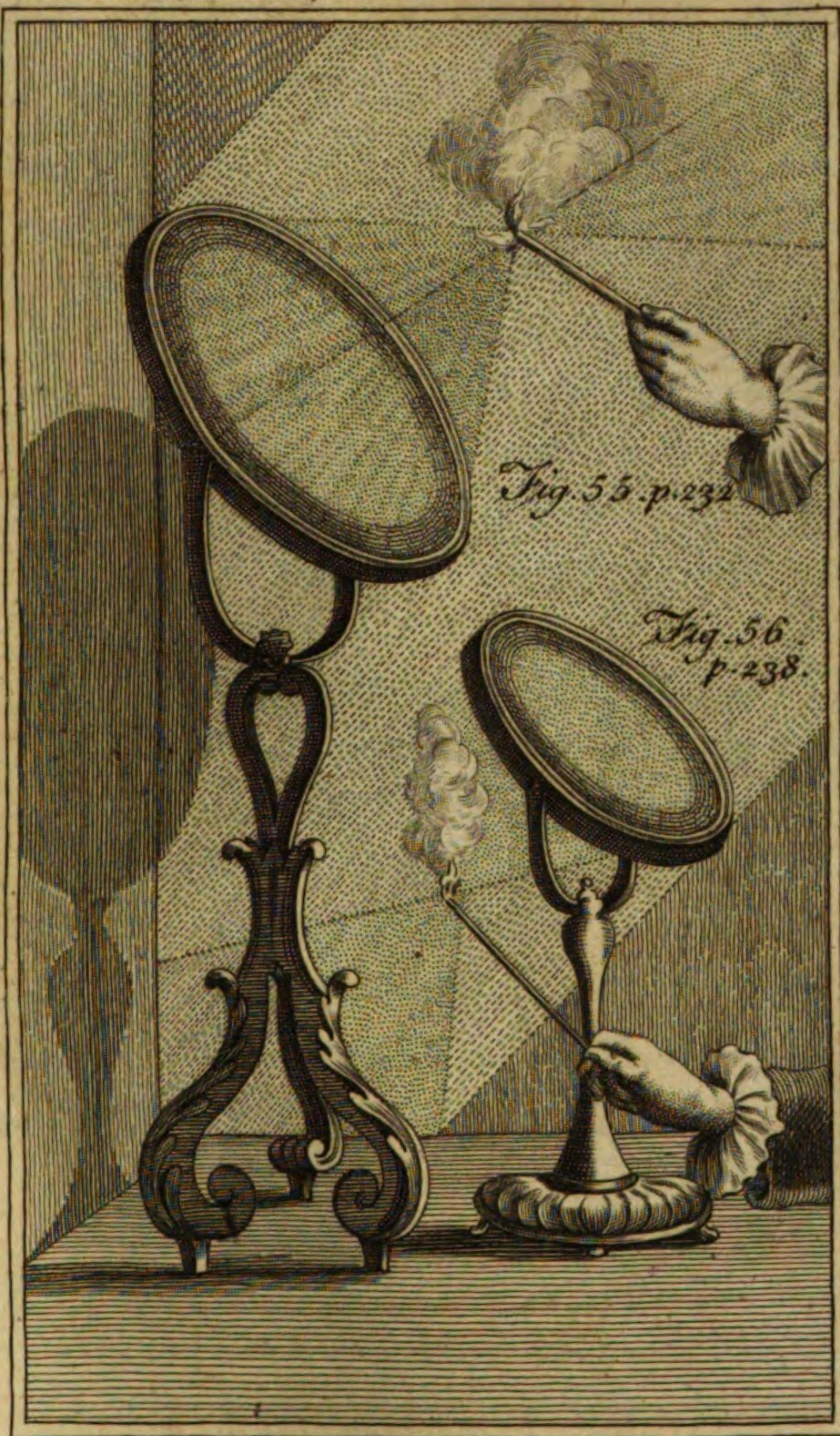
by the means of an oven alone, made use of an artificial hen made of wool to clutch the young brood when it came from the shell.

ALL bodies thus feel the influence of the sun's rays, in proportion as they strike against them more directly, or as the bodies are fitted for their reception. The rays, however, as they ever continue to operate, are, at the same time, restrained from burning too fiercely, by the nature and disposition of the bodies upon which they fall; the heat is diffused evenly through their parts; and never in the natural state of things, is it found to set the body in flames. To give the rays greater power they must be collected by art; and when their heat thus becomes united, they consume, or, at least, change all bodies whatsoever with inexpressible force. The hardest metals, steel itself melts, in a few minutes, into glass, and seems, by the violence of the heat, to lose its nature;
in

in a few minutes more, the metal begins to send up fumes, and, at last, is totally evaporated away, to mix with the air in which we breathe.

To give an idea of the manner in which the sun's rays are thus collected together, take six or eight small looking-glasses, and holding them opposite to the sun, let their reflected light fall all upon one spot, upon the crown of a hat for instance; if we put our hand there, we shall find the place much warmer than the sun would have heated it without the reflection. If we make the united reflections fall upon the ball, at the bottom of the thermometer, (see fig. 54) we shall then be perfectly convinced of the increased heat by the rising of the fluid in the tube. This experiment is easily tried, and the effects will always answer. Now, if instead of eight glasses we should use a much greater number, the heat will be augmented in proportion, in the body
I upon

upon which their united reflection falls. We have often said, that all circles may be considered as composed of a number of right lines; and spherical figures may be considered as composed of a number of plain surfaces. Instead, therefore, of a number of plain glasses, if we should make use of one concave mirrour, (see fig. 55) somewhat resembling, in shape, the internal surface of a pewter bason, this will throw the rays upon one point, and the body, which is placed exactly there, will be consumed in a time proportioned to the mirrour's size and construction. I am sensible that mentioning so vulgar an utensil as a bason, may incur ridicule; however, a very tolerable burning reflector may be made from one of these, newly taken out of the shop. For if a copper bason or dish formed of a true spherical figure, as some of them are, be well tinned on the inside. If then quicksilver be put into this vessel, and rolled about its sides, it will unite with the tin, and stick to its surface



Proud sculp .

as water would, and silver the whole surface over with as fine a polish as it assumes behind a plate of looking-glass, for that is only quicksilver and tin mixed together, as in this experiment. The basin thus polished on the inside will make a very good burning mirror, and will consume the densest bodies, if laid in the proper point where the reflected rays unite together. Such a reflector is only for those who will not be at the expence of such as are more powerful. The best are thought to be those made of polished steel, as this metal is hardest and best reflects the rays. Others recommend a composition of tin and antimony ; in short, each philosopher chuses the materials of his mirror ; and those, in general, are found to answer best, where the substance of which they are made is compact, bears an high polish, and is of a white colour ; for it must be observed, that such as are made of black materials, as of black marble, do not reflect the
rays

rays at all, or, at least, but very feebly ; for black is a quality which rather imbibes than reflects the rays that fall upon its surface. We have several accounts of the force with which concave mirrors, properly formed, destroy all substances put into the focus of their energy, for so is the point called, where all the reflected rays unite and burn fiercest. The mirror of Septala burnt at fifteen feet distance : Boerhaave says much of that made by Tschirnhausen. That of Villet's construction is equally admired ; it was near four feet in diameter, and burnt substances at a distance of three feet two inches with extreme violence. Iron ore placed in its eye or focus, melted in twenty-four seconds, bone was turned to glass in thirty-three seconds, a copper halfpenny had an hole melted through it in thirty seconds, and several other substances were consumed with equal rapidity. Boerhaave informs us, that with his mirror he has frequently turned gold to glass,

glass, but could never diminish its weight; others, however, assert the contrary, affirming that part of the gold is driven away, and a part remains behind, reduced, in a manner, to ashes, or, as the chymists call it, to a *calx* or *caput mortuum*. Such are the effects of mirrours of this construction; though it may be observed, however, that whatever metals are thus turned to glass or to ashes by the effects of heat, may be restored to their natural state by being united with charcoal, and so melted over again.

BUT whatever we are told of the effects of Villet's burning mirrour, they fall far short of what has been performed by a mirrour more lately made by Mr. Buffon; for this burns at a distance of no less than two hundred feet. This excellent naturalist justly considered, that if a plain looking-glass warmed at a great distance, a number of plain glasses, united to fall their rays upon the same spot, would actually burn; he therefore put
together

together several plain glasses, each about half a foot square, and so disposed as to have all their reflections fall upon one object, pretty much in the manner represented above. They are fixed in a frame which can alter their focal distance at pleasure, so that the same machine which throws the combined reflected rays to a distance of two hundred feet, may, by the turn of an handle, be made to throw their united force upon an object not distant above twenty. It is remarkable enough, that Tzetzes, a Greek writer of the twelfth century, giving a description of the manner in which Archimedes burnt the fleet of the Romans, assures us it was in the manner we have just described. Archimedes, he says, made a number of plain mirrors with combined force, collect the rays of the sun upon the vessels in the harbour, and thus he set them on fire. The mirrors of the ancient mathematician, however, must have been much more powerful than those of the modern naturalist;

naturalist; for Diodorus Siculus tells us, that Archimedes burnt the Roman fleet about three furlongs removed from shore. The moderns cannot conceive the manner in which this could be done, at so very remote a distance; so what they cannot understand they boldly deny; and assure each other, that Archimedes never burnt the Roman fleet.

POLISHED substances reflect the rays in greatest abundance; but no substance whatsoever is wholly destitute of this reflecting power. In fact, we have had some burning mirrors made of wood, of flax, and even of paper; itself a substance so easily capable of being consumed. We are told of a person at Vienna, who made one of these that melted iron. It would be strange enough to an uninitiated reader, when thus told that paper should be made to receive an heat sufficient to melt iron, and yet remain perfectly untouched by the fire itself. This
man's

man's name, if I remember right, was Neuman.

BUT the concave figure is not the only one by which the rays of the sun are thus collected together; for any transparent convex body that permits the rays to pass through it, will unite them in a focal point somewhere behind it. One of the glasses of a common pair of spectacles, if it be sufficiently convex (that is gradually rising in the middle) will burn wood, or any other substance that lies at the proper distance under its eye. We shall shew the manner how a convex glass thus directs the rays that pass through it in a point behind, in another place (see fig. 56). Let it suffice to observe here, that if so small a glass as that just mentioned has power to burn, what will not the power be of that made by Tschirnhausen, which was near four feet broad, an inch and an half thick, and whose focal point,
or

or that point where all the rays were most collected, was twelve feet from the glass, so that it burnt with its greatest force at that great distance. Stones, metals, earths, fled instantly away before it ; it was observable also, that its ardour was most efficacious, when the substance to be consumed was laid upon a piece of charcoal. Yet we must not suppose the effects of such a glass equal to those of the concave mirror mentioned before. From its figure it cannot unite the rays into so small a point as the former, and therefore must operate with less influence. Burning instruments of this kind are usually made with glass ; but any transparent substance that lets the rays pass freely through, will answer the end as well. An hollow glass of the proper shape filled with water, has all the same effect as solid glass would have. And this was known to the ancients, for Lactantius assures us, that a globe filled with water, would kindle a fire even in the midst of winter, which he thought still

the more surprising. A burning instrument may be thus made of horn, if very transparent, of Isinglass, of glue, of ice itself. In fact, ice makes an excellent burning instrument. Take a piece of ice, put it into a common brass ladle, and by melting, it will shape itself, in the bottom of the ladle, to the figure you propose, that is convex on one side and plain on the other. Use this as a burning glass, and it will answer rather better; particularly if the water has been boiled before it froze, so as to purge it of all its air.

THE effects of burning instruments, whether concave or convex, are great, always in winter, which is very extraordinary, since the heat which they collect is so much less at that season. However, there may be a very good reason assigned for this seeming paradox. Vapours are found greatly to diminish the efficacy of the rays collected by the ardent instrument; charcoal burning

ing and sending up its vapour under the converging rays, enfeebles them surprisingly. There are always less vapours in winter than in summer.

A burning mirrour not only collects the rays of heat, but of light also; sometimes giving luminary rays such a brilliancy as to dazzle, and, at last, destroy the strongest sight. Thus the light of the moon may be collected in the eye of a burning mirrour, with a splendour only inferiour to the united beams of the sun; but notwithstanding these beams are so very bright, they have no heat at all. Nor is want of heat in the moon beams to be wondered at; for by calculation it has been found, that the heat of this luminary is three million of times less than that of the sun; but our best instruments can make the beams either of the sun or moon, only three hundred times more powerful than they were before. So that the moon beams, even after they have been united to-

gether, are still a thousand times colder than the common heat of the sun in the ordinary state of nature.

DUFAY, a French philosopher, first tried the force of these instruments, in collecting the rays of a common culinary fire. Neither the concave mirror, nor the convex glass, would collect the rays of a charcoal fire, when single and alone; but by uniting their forces, he found that they had a moderate share of force. He first took a large glass convex upon both sides, so that the rays of the fire passing through it went out behind parallel to each other. These rays thus transmitted were received upon the surface of a concave mirror behind, which reflected them into a focus; however, they could burn only when the two instruments were but four feet asunder. So very much are the rays of a culinary fire enfeebled by passing through the pores of glass, while the solar rays, on the contrary, seem to lose
very

very little of their force. The heat of a common fire is thus composed of gross and massy parts, while that of the sun is penetrating, light, and active. Is it to be wondered therefore, that the juices which are nourished in the vegetable world by the solar heat, are light, pungent, and racy, while those which culinary heat produces in an hot-house, are more vapid and less highly flavoured?

IF a concave burning mirrour be placed before a large fire, it gives back the heat in a considerable degree, so as to be sensibly felt at thirty or forty paces distance. But it will not, however, be reflected into a focal point. An instrument of this kind might be useful in kitchens, to reflect, and thus double the heat of their fires. A learned Dutch writer advises cook-maids, in general, instead of the spherically formed mirrours, to make use of the true parabolic curve; for then it will reflect the rays most exactly parallel to its axis.

C H A P. II.

Of Cold.

COLD is a quality whose nature, like that of fire, is best known by its effects. Whatever are the properties of fire, those of cold seem to be directly opposite. Fire increases the bulk of all bodies, cold contracts them; fire tends to dissipate their substance, cold condenses them, and strengthens their mutual cohesion. But though cold thus seems, by some of its effects, to be nothing more than the absence and privation of heat, as darkness is only the privation of light; yet cold is seemingly possessed of another property, that has induced many to think it a distinct substance from heat, and of a peculiar nature. It is universally known, that when cold, by being continued, contracts and condenses

denfes substances to a certain degree ; if then its power be increased, instead of continuing to contract and lessen their bulk, it enlarges and expands them ; so that extreme cold, like heat, swells the substance into which it enters. Thus, in fluids, they contract sensibly with cold till the moment they begin to freeze ; from thenceforward they dilate, and take up more space than they possessed while in a state of fluidity. When liquor turns to ice in a close cask, it is often known to burst the vessel. When ice is broken upon a pond it swims upon upon the surface ; a certain proof of its being of a larger bulk than so much water.

WATER, after losing its fire, by means of which it remains in a fluid state, becomes more dense ; consequently its particles mutually touch in a greater number of points, and therefore cohere more strongly, to a degree, that water turns to a hard body, commonly called ice.

IF a very cold air is in contact with the surface of the water, there it first loses its fire : and thus the cause of its fluidity being removed, the upper surface of the water turns to a film or skin of ice, formed by oblong threads or filaments. And this is the reason why water usually begins to freeze on the surface,

As water in freezing becomes more dense after losing its fire, its intermediate spaces or pores become smaller, and being filled with air, this air comes to be compressed, and thus its elasticity being heightened, it forces out of the pores of the water, ascending in it, as being lighter than water, in the form of small bubbles ; and having reached the upper film of ice, their escape is there prevented, and thus they run into larger bubbles, when come into mutual contact. And this accounts for the great number of air-bubbles observable in ice. If by boiling, or by the air-pump, we discharge

discharge the air out of water, and then set it to freeze, the bubbles, it is true, will be fewer, but that it shall have none is not possible, because the air can never be all of it discharged.

AND thus the air forming bubbles in ice, must expand it, and cause it to occupy a larger space than water, and consequently render it lighter, and make it float on the water. It should therefore seem, that the ice of the water purged of air, should be of equal weight with it. But experience shews the contrary. For such ice laid on water floats in like manner, though sinking much deeper in it than other ice. And it is not possible it should be otherwise, as neither by boiling, nor by the air-pump, all the air can be discharged.

THE Florentine academicians attempting to discover the extent of the expansion of water when turned to ice, found that the space occupied by the water, was

was to that occupied by the ice to which it was froze, as 8 to 9. Again, they took a certain weight of water which they set to freeze, and filling the space occupied by the ice, with water, and weighing it, they found the weight of the first to that of the second water, as 25 to $28\frac{1}{9}$. Now 8 is to 9, as 25 is to $28\frac{1}{9}$. So that the ratio of 8 to 9 differs but little from that of 25 to $28\frac{1}{9}$.

FROM this extraordinary expansion of water, we may readily conceive why it cracks the glasses in which it freezes. Huygens filled a stout gun-barrel with water, securing it at both ends, and in twelve hours after it burst with a loud explosion. The Florentines filled a copper ball with water, and filing it down gradually, it at last burst, by the water froze in it. Muschenbroek, by calculation, found, that a force of 27,720 pounds was requisite to tear this ball asunder. At Petersburg, in the winter of
1749,

1749, an iron bomb was burst by water turned to ice. And we have instances of the havock produced in the substance of vegetables, trees, and even of splitting rocks, when the frost is carried to excess.

FREEZING is carried on much more expeditiously when the water is at rest than when it is in motion; it is easy to assign the cause of this, as the ice is carried from one surface to another by filaments, the current is still destroying them as soon as formed; and it would be as difficult for a spider's web to be formed while the wind was breaking and blowing the threads that formed it, as it is for the frost to send forth its filaments in the proper order, for the general congelation of a river. In very great frosts however, rivers themselves are frozen. I have seen the Rhine frozen at one of its most precipitate cataracts, and the ice standing in glassy columns like a forest of large trees, the branches of which have been newly lopt away.

BUT

BUT though the current of the stream opposes its freezing, yet a gentle and hot wind frequently helps it forward. Fahrenheit assures us, that a pond which stands quite calm, often acquires a degree of cold much beyond what is sufficient for freezing, yet no congelation ensues. If a slight breath of air happens in such case to brush over the water's surface, it stiffens the whole in an instant. The water before congelation and in its liquid state, sinks the thermometer very low, which shews itsexcessive degree of coldness. The moment that by the air, or any other agitation, it begins to congeal, the thermometer rises to the ordinary freezing point. The causes of all these are inscrutable in the present state of philosophical experiments.

IN general, the ice of northern regions is much harder than that of the more southern climates; and though it contains more air, yet its contexture is much stronger by reason of the greater degree
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of cold by which it is congealed. The ice of Spitzbergen and the Greenland seas is so hard, that it is very difficult to break it with a hammer. In our own climate we may, in general, form a very just conjecture, concerning the duration of frost by the hardness of the ice. If in the beginning of the frost, the ice is harder and more resisting than usual, it is a sign that the frost will continue long in proportion. A machine might with a little ingenuity be made, that would discover this hardness with sufficient precision. During the hard frost of 1740, a palace of ice was built at Petersburg after the most elegant model, and the justest proportions of Augustan architecture. It was fifty-two feet long, and twenty feet high: the materials were quarried from the surface of the river Neva, and the whole stood glistering against the sun with a brilliancy almost equal to his own. To increase the wonder, six cannons of ice, two bombs,

bombs, and mortars, all of the same materials, were planted before this extraordinary edifice. The cannon were three pounders, they were charged with gunpowder and fired off; the ball of one of them pierced an oak plank at sixty paces distance and two inches thick, nor did the piece burst with the explosion *.

IN melting of ice, if it be laid upon some substances it melts faster than upon others, nor can we assign any cause for the difference; it melts sooner in a silver plate than upon the palm of the hand, and it melts sooner upon copper than on any other metal whatsoever. Ice melts sooner in water, than exposed to the air of a similar temperature. Sooner in water a little warm than near the fire when it is hotter. It melts sooner in the void, than exposed to the atmosphere. If it takes twenty minutes

* M. de Mairan Dissert sur la Glace. Part. II. Sec. 3. Chap. 3.

to dissolve in open air, it will be but four minutes dissolving in the exhausted receiver.

THOUGH ice be a hard body, yet it is subject to a constant evaporation when the cold in the air is excessive. Perrault found, that four pounds of ice, which lay exposed for 19 days in the open air, was lighter by a whole pound. M. Mairan, in the year 1716, in which, for some days, the cold was as severe as that of the winter 1709, also found that ice, which had lain in the air and in a northerly wind, had lost in 24 hours above a fifth in weight: from which we may, at the same time, perceive the reason, why snow, lying exposed in a continued cold on the earth, becomes diminished in quantity.

WE have hitherto considered cold and freezing, as effects arising barely from the absence of heat. There is, perhaps, something actual or real in this case;

case ; possibly a body, which expels the particles of fire out of other bodies, while itself forces into their pores, and thus coagulates the fluid matters ; that is, constrains or binds their parts, in such a manner as to cohere strongly together. The diffidence which one should entertain concerning his conclusions, gives weight to this thought, and the experiments performed with salts will enhance it.

IF a thermometer is set in cold water, and you remark how far the spirit sinks ; then throwing in saltpetre, you will observe the spirit to sink deeper still, after the saltpetre is dissolved in the water. The same thing happens, if instead of saltpetre, you use common salt, or which is better, sal ammoniac.

WATER congeals in a glass which is set in salted snow : and, if only the under part of the glass stands in the snow, the congelation happens from below

low upwards, and then we may plainly perceive the manner in which the air is discharged out of the water. In this case, the glass does not readily spring or fly; but if you cover it entirely with salted snow, in order to promote a congelation all over, and thus prevent the discharge of the air, the glass flies.

As heat expands solid bodies, so cold contracts them. On the expulsion of the heat, the parts of the body draw closer together, and thus their matter is reduced to a smaller compass. Now, as a body becomes cold on losing its heat, it becomes denser in the proportion of the cold; and yet not in an infinite progression, nature setting bounds to both.

COLD and heat affect the pendulum rod of clocks, the first contracting or shortening, and the last dilating or lengthening it, and thus altering its motion; which is attempted to be remedied, by

opposing expansion to expansion, and contraction to contraction.

IRON is hardened by cold, upon making it first glowing hot, and then quenching it in cold water or moist loam; these are bodies which quickly deprive iron of its heat; and being thus cooled at once, it becomes denser, its parts coming closer together; and thus touching in a greater number of points, they cohere the more strongly, and consequently the iron is made harder.

THE Thermometer is the common measure for the degrees of heat and cold; but whether a just one may be doubted. And first, the glass of the thermometer expands with heat, and thus hinders the ascent of the spirit, and contracts with cold, thus preventing its fall. Then, in a great degree of cold, the air is discharged out of the spirit, and fills that part of the glass which should have no air, and by its elasticity opposes the rising

rising of the spirit. And lastly, it is supposed, though groundlessly, that the heat is proportional to the expansion of the spirit, though the contrary appears by the pyrometer.

IF you pour water on a table, and place on it a tin plate with salted snow, the plate will be frozen to the table, as soon as this snow begins to melt. For as the water is much warmer than the salted snow, the fire must force out of the water into the plate, and from this last into the salted snow. And thus the water losing its heat, turns to ice; and on the contrary, the snow being heated, must melt, before which the plate is not froze to the table, the particles of fire being then gone over into the snow out of the water. This experiment may be made, though you set the plate with the salted snow over glowing coals, kept constantly blowing. On the plate with the snow lay another plate with cold water, and stirring with a cane, or any

other instrument, the snow will dissolve, and ice will be formed upon the water in the dish. I have tried it frequently without salt, and it answers, though not with equal efficacy.

BUT by this method we can only then make ice when we are possessed of snow or ice already: Boerhaave gives us a method of making ice without them. We must have for this purpose, at any season of the year, the coldest water we can get; this is to be mixed with a proper quantity of salt, at the rate of about three ounces to a quart of water; another quart of water must be prepared in the same manner with the first; the salt, by being dissolved in each, will make the water, as was said above, much colder than it was before; they are then to be mixed together, and this will make them colder still. Two quarts of water more prepared and mixed in the manner of the two first, are to be mixed with these, which will increase the cold
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in a much higher degree in all. The whole of this operation is to be carried on in a cold cellar; and a glass of common water is then to be placed in the vessel of liquor thus artificially cold, which will be turned into ice in the space of twelve hours. Of all salts, *sal ammoniac* best answers this intention.

BUT of late there has been a more effectual method of congealing fluids than any yet mentioned. It has been discovered, that fluids standing in a current of air, grow by this means much colder than before: it has been discovered also, that all substances grow colder by the fluids they contain, or are mixed with, being evaporated. If both these methods therefore are practised upon the same body at the same time, they will increase the cold to almost any degree of intenseness we desire.

THE Russian experiment at Peterf-
burgh of congealing quicksilver was thus :
at a time when the quicksilver was
found to have fallen extremely low, and
the cold consequently to be very intense;
the mercury being by De Lisle's thermo-
meter, which is best adapted for measur-
ing the degrees of cold, as Fahrenheit's
for measuring those of heat ; being I
say, by this thermometer, fallen to 250
degrees, they increase the cold by mix-
ing the fuming spirit when it becomes
red, and being left to cool in snow, with
half as much snow in a common glass,
stirring it till it becomes of the consist-
ence of pap in the usual manner, by
a mixture of spirit of nitre with snow ;
the thermometer being dipped into this
composition, the quicksilver sunk to
470 degrees. Upon a repetition of this
experiment, when the mercury (which,
contrary to the manner of water, instead
of dilating, still continued to contract
with increased cold) sunk to 500 de-
grees, they broke the glass, and it was
found

found frozen into a hard solid mass; but what is most extraordinary, it bore the hammer like a common metal, and was beat into the shape of an half-crown. At last, however, it began to break, and being thawed, recovered its former fluidity. From hence we see, that the spirit either of salt or nitre are possessed of the power of cooling liquors in a much higher degree than the common substances in concrete. Common nitre, or saltpetre, for they are the same, sinks the thermometer to eleven degrees. Spirit of nitre will be found to sink it eight degrees still lower, as has been discovered by Fahrenheit.

C H A P. III.

O F L I G H T.

AS by the degrees of cold or heat in bodies, we are led to estimate the quantity of fire they contain; so also we have another method of assuring ourselves of the existence of fire in different substances, by the light they send forth; for wherever there is light, there is fire. Heat and light may be considered as the children of fire, as kindred qualities produced by the same cause, but sometimes exerting their powers separately, and sometimes united. It is the same fire, whose heat burns in the melting metal unseen, and whose light shines harmless in the glow-worm. This light, though seemingly inoffensive, would burn if collected into a small compass, like the fiercest flame; but no instruments that art has yet found out, are able to give its parts a sufficient consistence.

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The flame which hangs over burning spirit of wine, we all know to scorch with great power; yet these flames may be made to shine as bright as ever, and yet be perfectly harmless. This is done by placing them over a gentle fire, and leaving them thus to evaporate in a close room without a chimney: if a person should soon after enter with a candle, he will find the whole room filled with innoxious flames. The parts have been too minutely separated, and the fluid perhaps has not force enough to send forth its burning rays with sufficient effect. However this be, we may safely conclude, that the parts of fire may be so separated, as to become harmless, and yet they may retain all their former splendour.

SINCE we thus see light and heat are the most obvious indications of fire, we have no reason to doubt, but that the sun, who is the great fountain of both, is itself one large body of that element.

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In what manner that great fiery mass is fed, with continuing fuel to keep up his force, is a question equally useless and impossible to be resolved; whether comets travel from other systems with a provision of this nature, or whether the ethereal vapours come from all parts with their supply, is not worth enquiring after. He that made the comet sweep through immeasurable tracts of space, could with equal ease give permanent fire to the sun: we feel the constancy of his flame, and can see scarce any diminution of his splendour. It is enough for philosophy to investigate the nature of this heat and light; the things with which man has the nearest concern, should be the chief objects of his curiosity.

SETTING aside other systems therefore, we know that the rays of the sun's light and heat are darted forward from his body in straight lines. If we make a small hole in a dark room, and permit a ray
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of the sun's light to enter, we shall see it dart against the opposite part of the wall or floor, in the straightest line. Did the beams of the sun diffuse themselves in any other manner, for instance as water or air are known to do, the ray, upon once entering the room, would soon fill the whole chamber with light: but this we know to be contrary to every hour's experience. The rays of light therefore dart directly forward from the sun, and reach our earth with the swiftest progression. It might by the uninitiated be thought a task beyond the reach of human abilities to calculate exactly, how long a ray of light is upon its journey, in travelling from the sun to enlighten our hemisphere. Yet this has been attempted by Romer, who finds that light travels at the rate of an hundred and fifty thousand miles in a single second; and that it is seven minutes in passing from the sun to the earth, which is nearly a distance of seventy millions of miles. The student
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may desire to know how he made this calculation, it was thus :

WHEN the earth in going its annual revolution round the sun is at C, (see fig. 57.) an eclipse is observed of a satellite of Jupiter, which thus regularly suffers eclipses every forty-two hours and an half. If the earth never left C, but continued there immovable, it would regularly see the satellite eclipsed at the expected interval of forty-two hours and an half: and also at thirty times that number, the spectator would see thirty eclipses. But the earth is not fixed; it travels onward to D, and a spectator does not see thirty eclipses in the stated period, and not till some minutes after; for the further off the earth removes, the light takes so much time to travel across the annual orbit from C to D. From C to D it takes up about sixteen minutes in travelling. Now the sun is nearly half-way between C and D, and therefore the light travelling from him, must

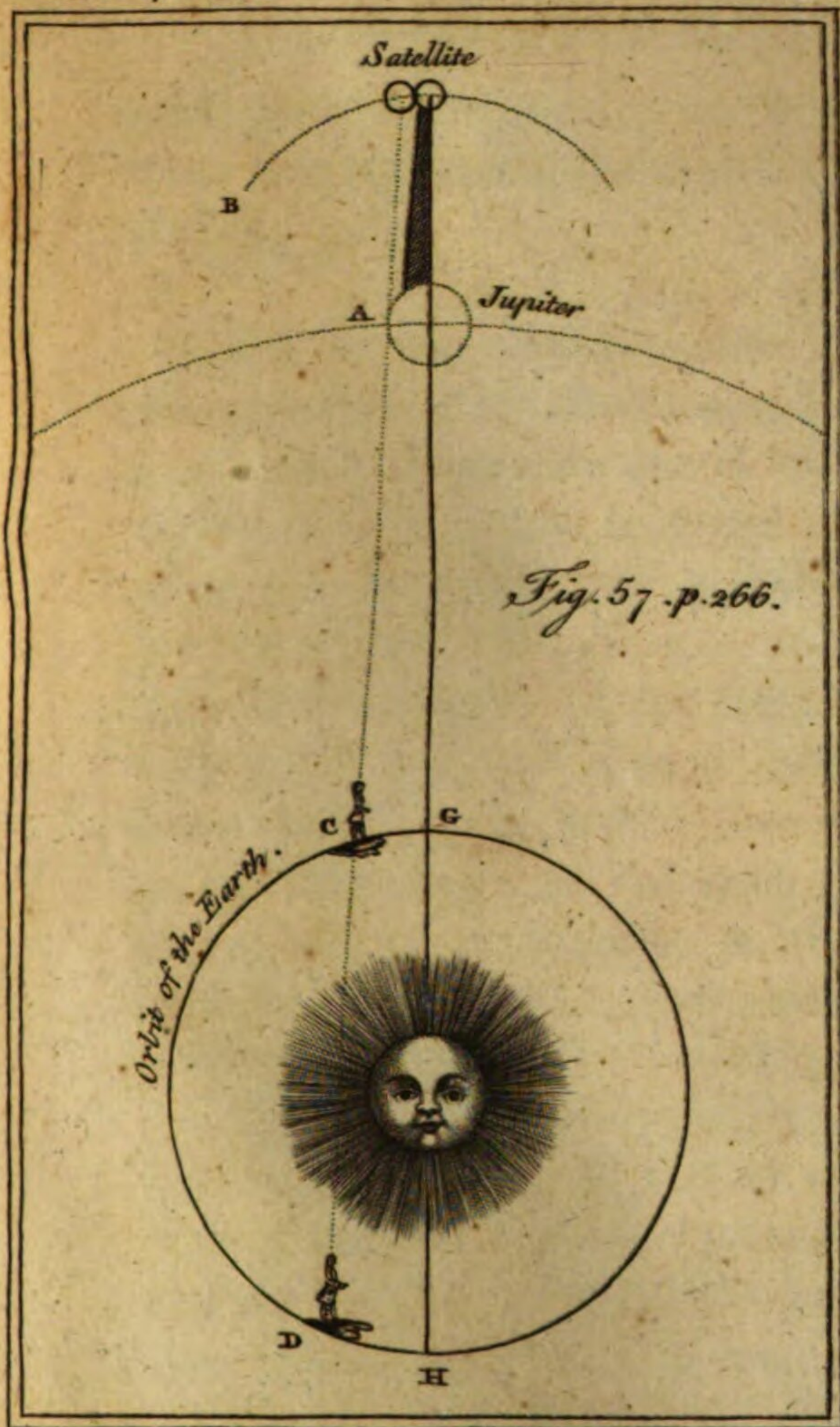


Fig. 57 .p. 266.

Proud sculp.

must perform its journey in half sixteen, that is, in eight minutes, or thereabouts.

SUCH is the rapidity with which these rays dart themselves forward, that a journey, they perform thus in less than eight minutes, a ball from the mouth of a cannon would not complete in several weeks. But here it may be said, if the velocity of the light is so very great, how is it that it doth not strike against objects with a force equal to its swiftness? If the finest sand, the objector may continue to observe, were thrown against our bodies with the hundredth part of this velocity, each grain would be as fatal as the stab of a stiletto: how then is it, that we expose without pain, not only other parts of our bodies to the incursions of light, but our eyes, which are a part so exquisitely sensible of every impression? To answer this objection, experiment will inform us, that the minuteness of the
parts

parts of light are still several degrees beyond their velocity ; and they are therefore harmless, because so very small. **A** ray of light is nothing more than a constant stream of minute parts still flowing from the luminary, so inconceivably little, that a candle, in a single second of time, has been said to diffuse several hundreds of millions more particles of light, than there could be grains in the whole earth, if it were entirely one heap of sand. The sun furnishes them, and the stars also, without appearing in the least to consume, by granting us the supply. Musk, while it diffuses its odour, wastes as it perfumes us ; but the sun's light is diffused in a wide sphere, and seems inexhaustible.

His rays travel onward without hinderance or mutual interruption ; winds meet and destroy each other's force, but the rays of light never oppose their mutual progress. If we place a row of candles (says the sensible Mr. Ferguson)

Ferguson) on a table, and let them dart rays through a pinhole in a piece of black paper, these rays being received upon any object not too far off, will be formed into as many specks of light, as there are candles ; each speck being distinct and clear, the rays from one candle being no way destroyed, by any interruption of those from another. The rays of a torch may be overpowered, and seem lost in the brighter rays of the sun, yet still the smaller candle actually shines with undiminished radiance ; as we may see by looking at it by night and by day through a telescope.

As light is thus driven forward in rays from a center, it must decrease, as all rays do, in proportion as the distance squared becomes greater. Gravity, sounds, and light are, in this respect, similar ; a luminary that enlightens the mountain's side at a mile distance, will illuminate four times as feebly at two miles distance. If I can but just read
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with a candle placed a yard from me, I must have four candles if they are placed two yards off. In a word, the quantity of light decreases inversely as the square of the distance.

To make any body visible, it is necessary that the rays of light should fall upon it; otherwise it will paint no image on the eye, nor transmit any but that of darkness to the mind. Objects placed in a dark room cannot be seen; but if the sash be lifted up, and the light be thrown in a greater quantity, we may have a confused idea of the figure of the furniture; however, until the room be entirely illuminated, and the rays that fall on every object be reflected back to our eyes, we can have no distinct perceptions. For this reason, a person who remains himself in the dark with an hole to peep through, can see all objects without, because their rays can be reflected to his eye; but, as was said before, he cannot from without see clearly
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into a dark room, because there are too small a number of rays sent from thence to form the picture of the object in his eye.

WHEN I use the word Picture, it should be understood in the most literal sense. Every object that we behold has its picture drawn most exactly, and in colours far beyond the reach of art, on the back part of the eye. To be convinced of this, we have only to take the eye of an ox or sheep, and stripping off all the coats to the last internal one behind, place it so in the hole in the window shutter of a dark room, so as that no light whatsoever shall enter but through the eye itself thus prepared. Then taking a sheet of white paper, and holding it nearer or farther off behind the eye, the spectators will perceive a most beautiful picture of the objects without thrown upon the paper, through the humours of the eye. Every object, however, will be inverted upside down

upon the paper, or, as the vulgar expresses it, they will all stand upon their heads, the cause of which demands explanation.

BUT before we enter into a more minute illustration of the manner in which vision is performed, we must explain more minutely the nature of light itself, by which the eye is thus made capable of seeing.

C H A P IV.

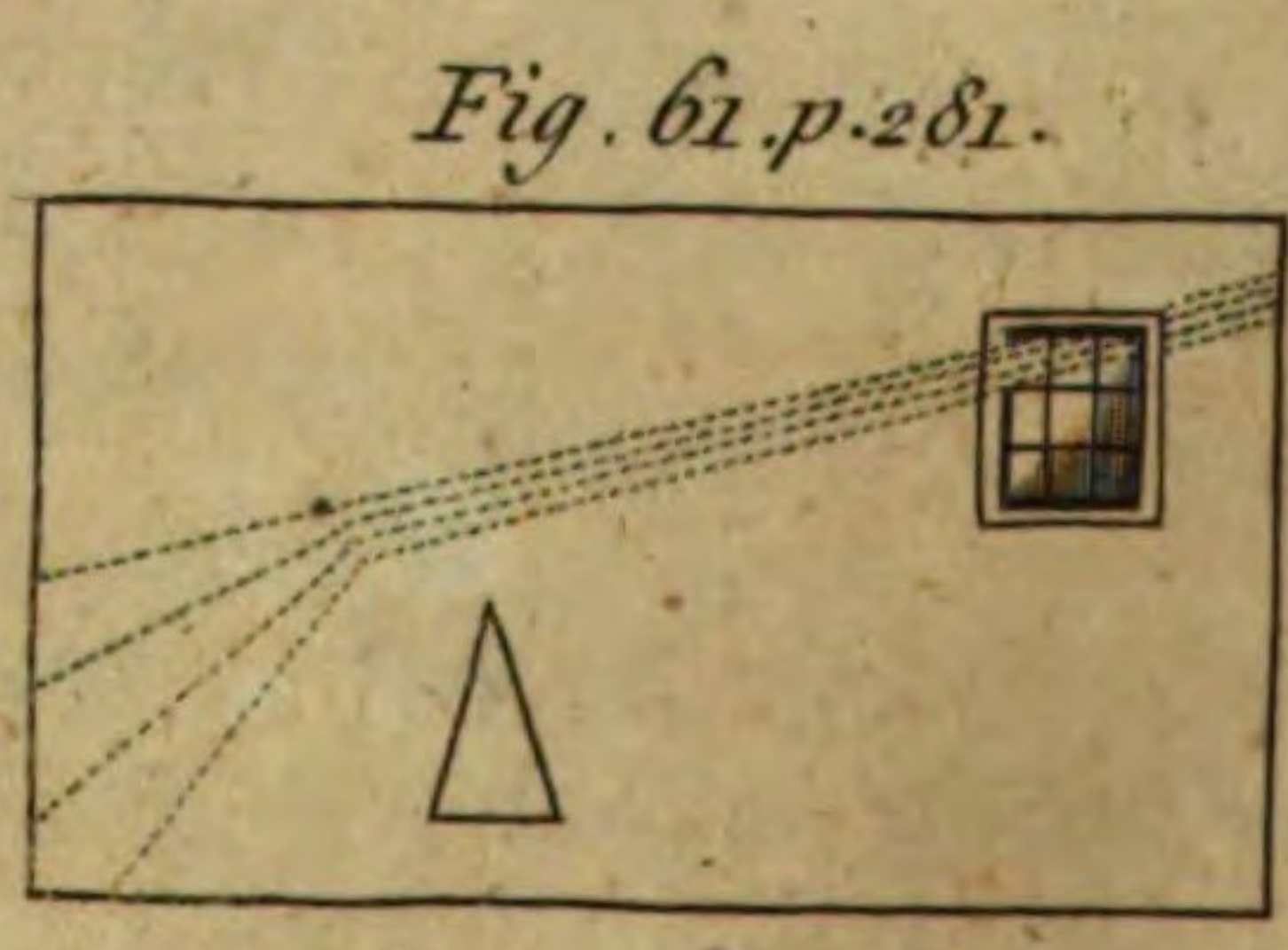
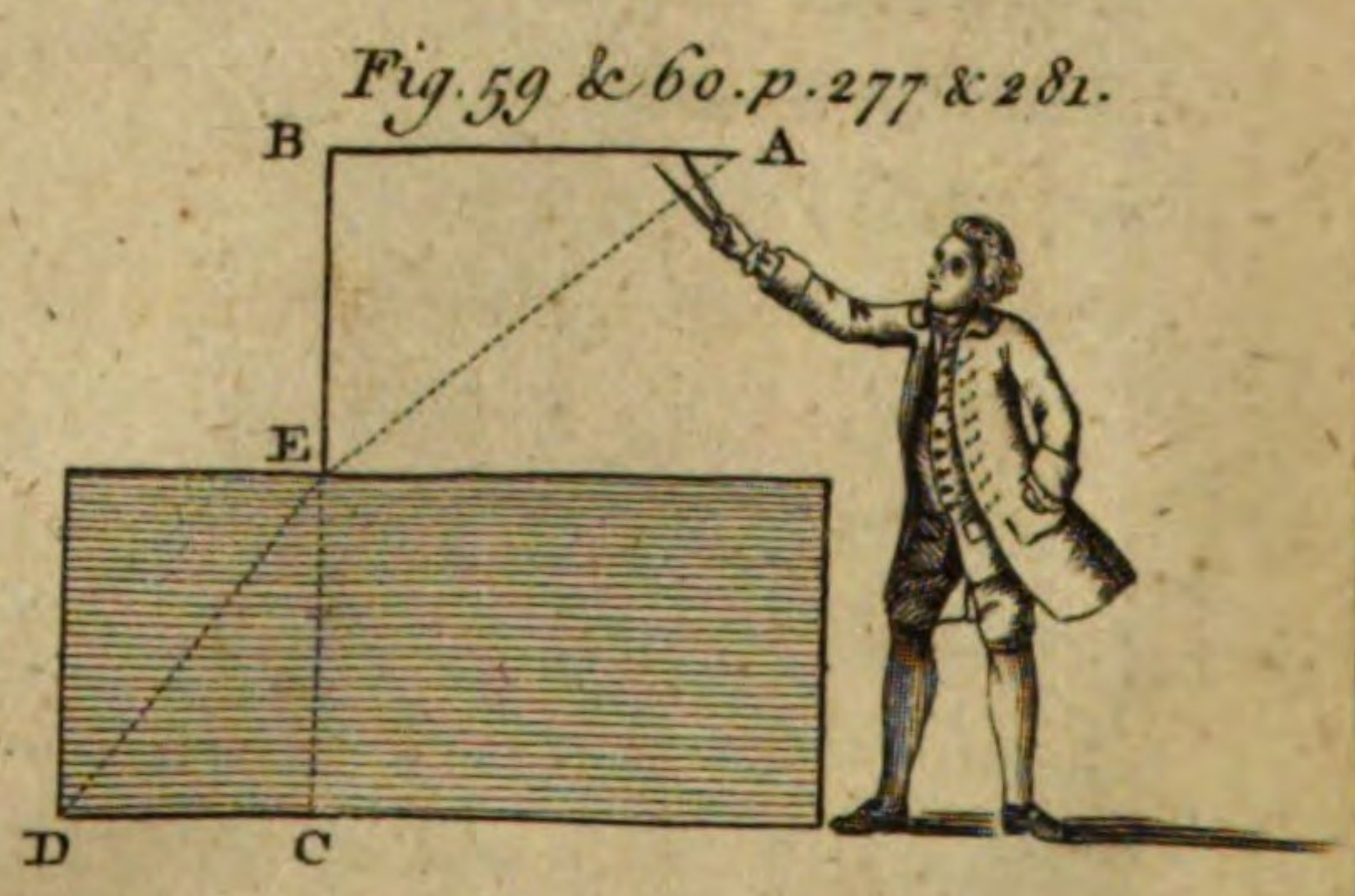
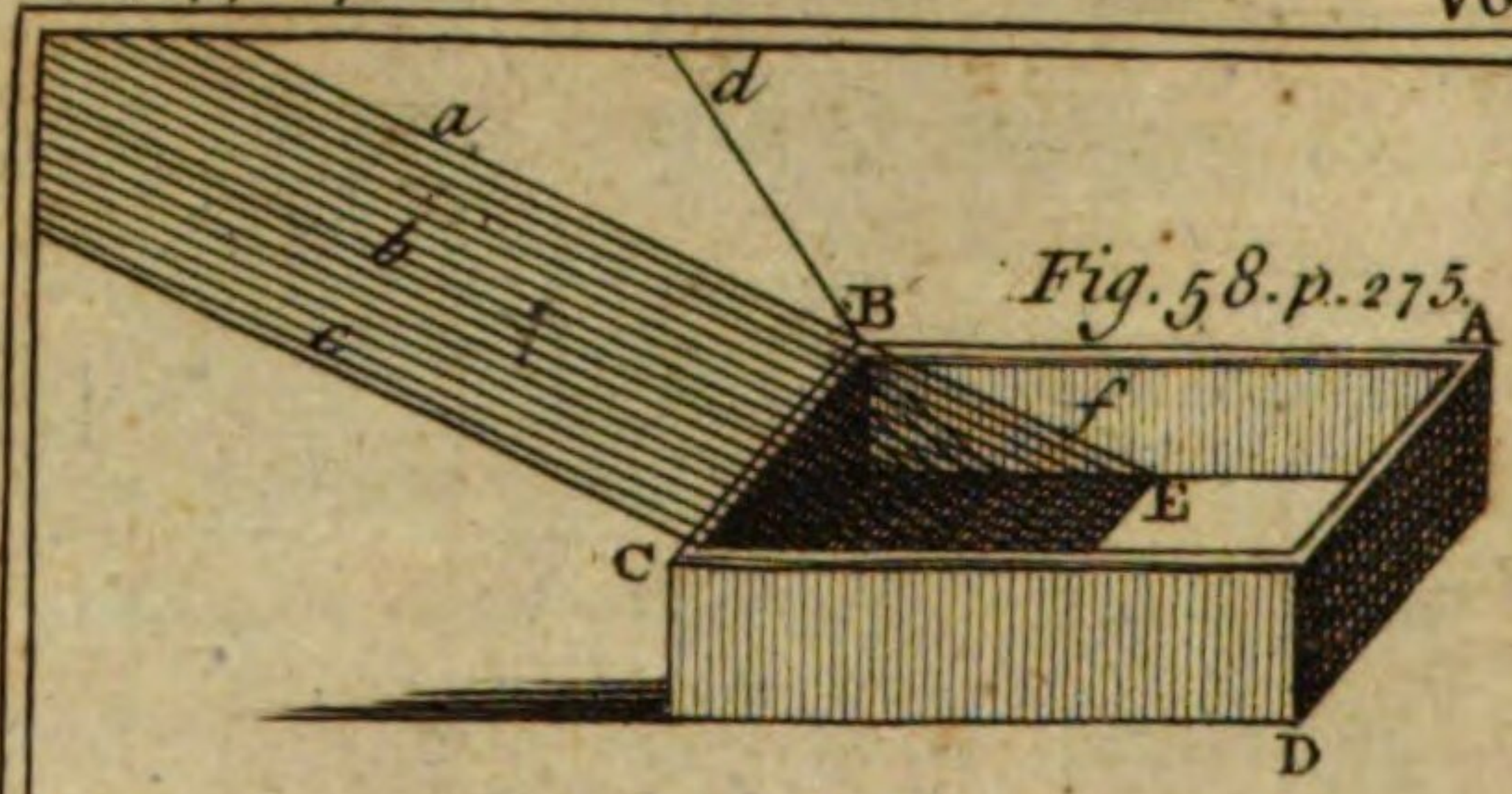
Of the Refraction of Light.

WE have seen that the parts of light are extremely small, and flow from the sun with inconceivable rapidity. We observed also, that they darted from that great luminary in straight rays ; but this is not entirely the case, for the rays may be bent into crooked lines by passing through transparent bodies of different densities. We see a stick when put into water, appear as if it were broken, at the surface of the water, in two. We see through some glasses bodies appear enormously large, and through others they appear extremely little. Through some they seem near, and through others remote. From whence arise these strange appearances, or what is the cause which thus bends the straight stick seemingly into a curve; apparently that magnifies the bulk of one object, or diminishes that of ano-

ther ? All these wonders arise from the same cause ; the rays of light, in passing through different transparent substances, take different directions. To explain this :

PHILOSOPHERS have agreed to call any transparent body, through which light passes a *medium*. Air is a medium ; water, glass, diamonds are mediums ; wherever light passes, though it be a vacuum itself, they call that a *medium*. Now, while the rays of light dart through any medium of uniform density, they are straight ; but when they pass obliquely through one medium into another, then they are *refracted*, broken, or driven out of their right lined course into a crooked direction. As a straight stick one half in the medium of water, and the other half in the medium of air, appears broken in two, just where the two mediums unite.

To shew that a ray of light is thus refracted by passing from air to water,
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an easy experiment will suffice. Let a sun beam be permitted to enter into the room by an hole ; but it is not necessary that the chamber should be darkened for this purpose. Then set an empty vessel, as A B (see fig. 58) in such a position, that the ray shall first glance upon the edge of the vessel, and then fall upon the bottom. Put a shilling at the bottom E. where the ray falls ; then fill the vessel with water. We shall find that then the ray will not fall upon the shilling at E, but fall nearer under the edge B C. So that the ray will now fall more perpendicularly to the surface of the water, than it would if it had suffered no refraction.

As the ray is thus refracted or broken more into the perpendicular, in passing from the air into the water, so will it be refracted, in a contrary way, in passing from water into air. For, let us suppose, the vessel once more empty, and the shilling at E hiding its rays from the spectator's

eye, at F. If the vessel be then filled with water, the rays of light, now passing from the denser medium of water into the thinner medium of air, will first mount up almost perpendicularly to C. and then getting into the air will pass more obliquely forward to hit the spectator's eye. So that the shilling will thus become visible. Just thus the ferrel of my cane, if put into the water, would appear raised, like the shilling; and therefore, if the ferrel be raised, the other parts of the cane that are in the water, must also be raised nearer to the eye, so that it will appear broken in two, just where the air and water meet. Thus then, we have seen that a ray of light, passing from a thinner medium into a denser, as from air into water, is refracted more directly downward, or more perpendicularly to the surface of the dense medium. On the contrary, the ray, passing from water into air is, upon its entrance into the air, sent forward more obliquely. Hence then, we
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may universally conclude, that the denser the medium, the more perpendicularly to its surface are the rays of light refracted. To give the learner the most distinct ideas possible of this, we said, the refraction of light was greatest in the densest mediums. Suppose the ray A E (see fig. 59) falls upon a vase of water, it is refracted from the straight line at the surface of the water to D. Let us suppose the perpendicular B E C drawn to the surface of the water, the ray of light A E makes an angle with the perpendicular B. It also makes a different angle with the same perpendicular, in going from E to D. The difference between these two angles is that which measures the greatness of the refraction of the ray. The two angles always bear a constant proportion to each other. The greater the angle A B, the greater will be the angle D C. To know the names used in science is, at last, become a part of science. The

angle B A thus made by the perpendicular and the ray, before refraction, is called the angle of incidence. The angle D C, made by the same lines, after refraction, is called the angle of refraction.

Now then, a ray of light passing from air to water, is found by experience to have its angle of incidence B A, bearing the same proportion to its angle of refraction D C as three does to four; or in other words, it is a fourth part greater in the air than in the water. In glafs, the angle of incidence is a third part greater than the angle of refraction, the proportion being about three to two. Diamond refracts most of all, the angle of incidence being three times greater than the angle of refraction.

FROM hence then we may be assured, that the denser the medium, the more perpendicular

pendicular does a ray of light, falling on its surface obliquely, pass through it; that is, it takes the shortest way. It takes a shorter cut in passing through diamond than glass, and through glass than through water; so that we see, the denser the body the more readily it pervades them. This is very extraordinary, and very different from the nature of other bodies, passing through obstructing mediums. If I should throw a leaden bullet obliquely into the water, it would not reach the bottom in the direction I had given it, but the water would in some measure keep it buoyant, and it would come with a greater slant to the bottom. But it is very different with a ray of light; when it darts obliquely on the surface of the water, it then begins to descend more perpendicularly downwards. What can be the cause of this extraordinary diversity in the operations of nature? Several philosophers have attempted this solution in vain :

vain: Newton attempted, and it no longer appeared a secret. The cause of light being thus perpendicularly refracted by the most dense mediums, is, that the parts of it are most attracted by the most dense mediums. All bodies as we well know, attract and are attracted in proportion to their quantity of matter. The light, from its minuteness, passes with equal ease through the hardest diamonds or the softest air; it meets in the densest mediums nothing to retard its progress, but much to increase its celerity, for it obeys the influence of their superior attractions. Every instant of its descent or progress through the denser mediums, it feels new influence from the attracting power. A bullet thrown from the hand obliquely into water, goes downward yet more obliquely; for the water in some measure, takes off from its natural gravity and keeps it buoyant: a ray of light, on the contrary, darting obliquely upon the water, has
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the obliquity of its fall interrupted by attraction, and consequently falls more perpendicularly down; though, rigorously speaking, the ray, in its descent through water or glass, is not refracted from the surface to the bottom in a straight line, but a crooked one; so that the line from E to D (see fig. 60.) is an absolute curve.

THAT bodies have this power of attracting the rays of light, may be known from the following easy experiment. Set a small pointed penknife standing with its point upward; (see fig. 61.) let the room be made perfectly dark, and a ray of light be permitted to glance in, so as just to touch the point of the penknife: the ray, upon touching the metal will bend itself in such a manner, that the part of it which is nearest the point, will be most refracted, and that farthest from the point, will suffer the least refraction; a proof, that the metal attracts
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those nearest it with the greatest force. If the point thus can refract the rays by its attracting power at a small distance, any dense substance through which they pass must more powerfully attract them, as the distance is nothing.

C H A P. V.

Of the Passage of Light through Glass.

WE have seen the manner in which water refracts the rays of light that pass through it; but the consideration of that part of the subject, though pleasing, is only a matter of curiosity; an investigation of the manner of its refractions through glass is connected very nearly both with our necessities and pleasures. When a ray of light passes out of air into glass, its angle of incidence is to its angle of refraction, as we said above, as three to two; that is, the angle of incidence is a third part larger than that of refraction: upon this single principle depends the whole theory of vision through glasses.

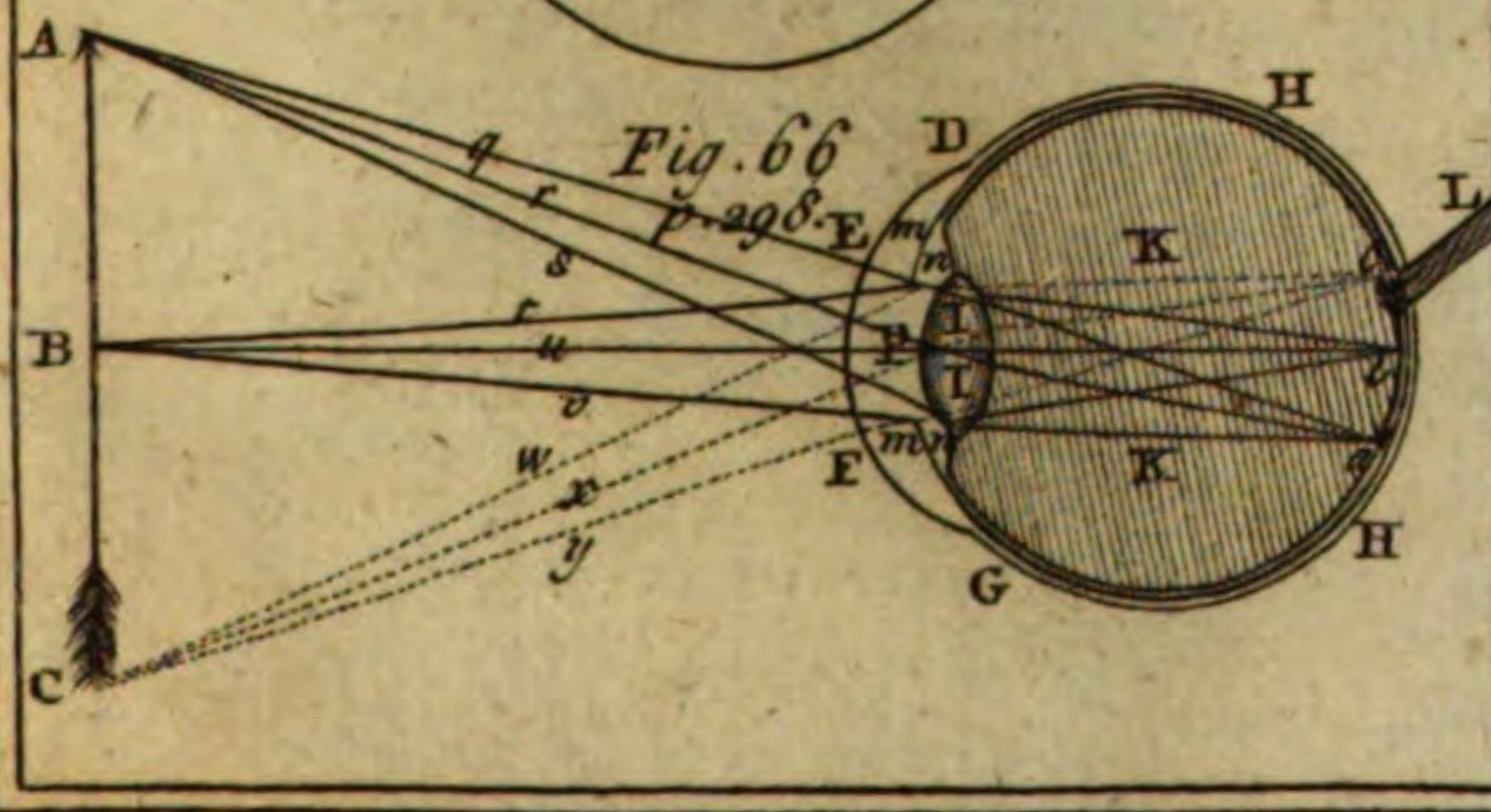
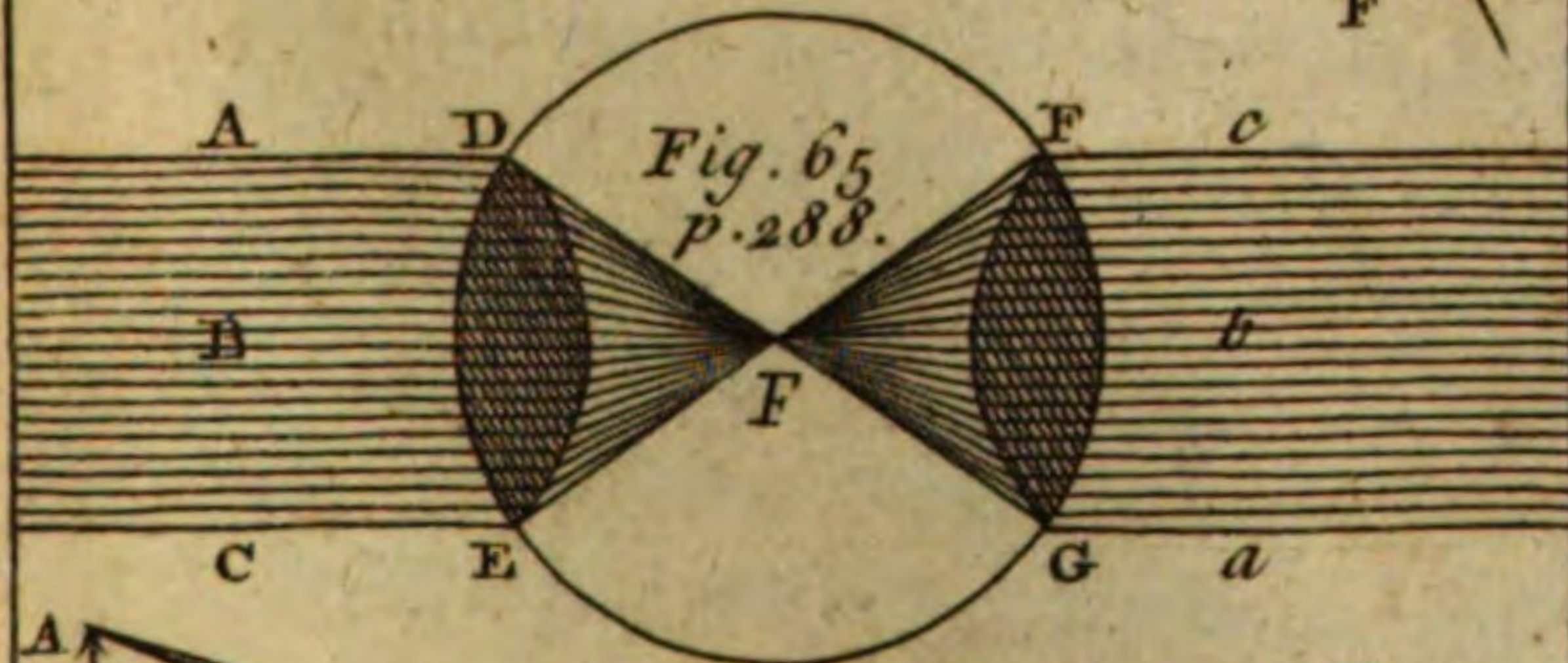
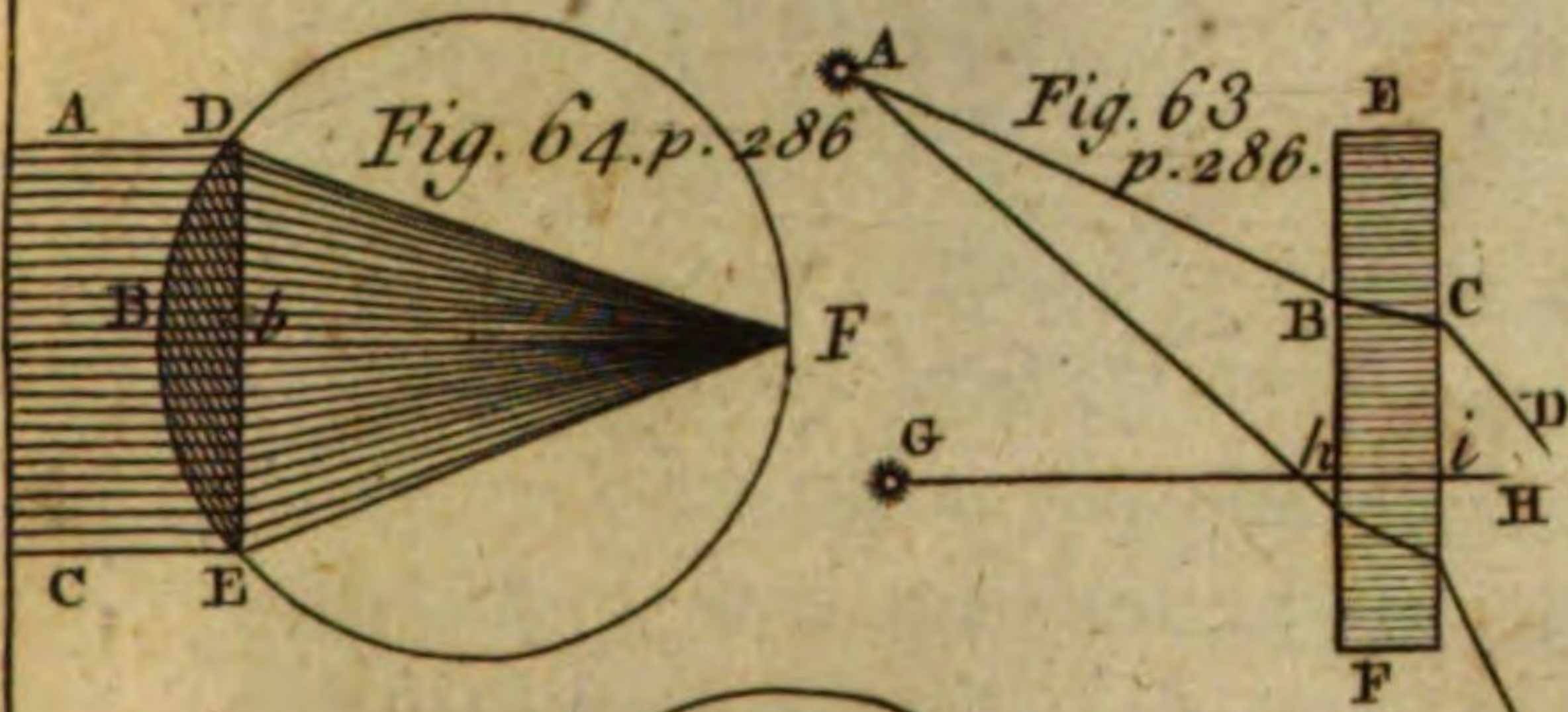
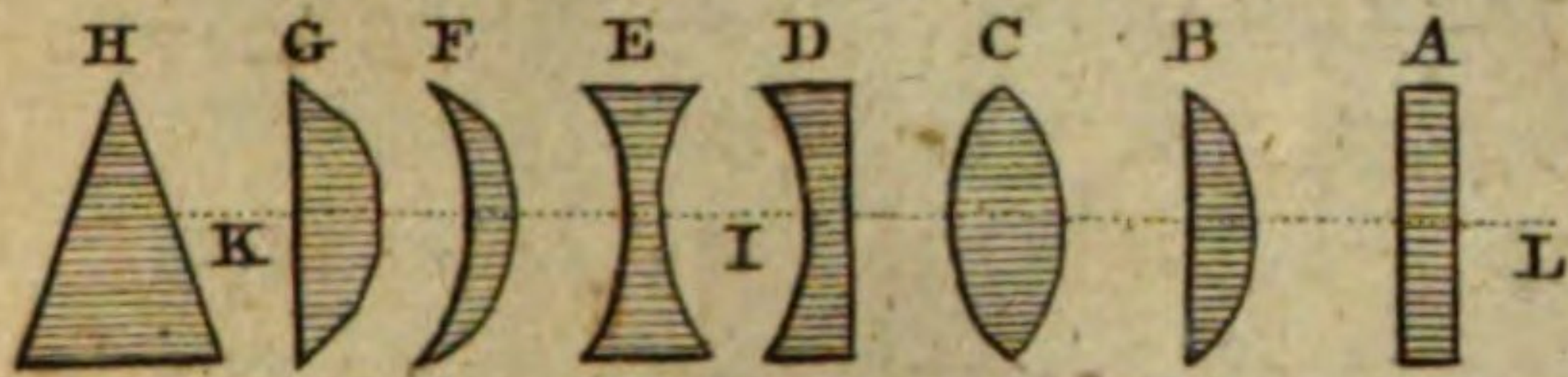
Glasses are usually ground by the glass-grinders who deal in this subject, into eight different shapes. For first, the glass may be flat on both sides, as
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the common pane of a window. Or 2dly, it may be flat on one side and convex on the other, B A (see fig. 62) Or, 3dly, it may be convex on both sides, like our ordinary reading glasses, C. Or, 4thly, it may be flat on one side and concave on the other, as D. 5thly, It may be concave on both sides, like the glass near-sighted people generally use, as E. 6thly, It may be concave on one side and convex on the other, like the crystal of a watch, though not in such a degree, as F ; this is usually called a meniscus. 7thly, It may have one side, which must be convex, ground into little facets, like those of some jewels, while the other side is plain. Children know it by the name of a multiplying glass, as G. 8thly, A prism, which from its importance in explaining several properties of light to be mentioned in the sequel, I should have named first. The prism is a longish piece of glass which has three flat sides, besides the two ends. I do not well know, even by a cut, how
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Pl. 18. p. 284.

Vol. II.

Fig. 62. p. 284.



Proud Sc

to give the learner an idea of its figure. A three square razor strap, as the vulgar express it, will give a resemblance of the prism. I have seen the shank of a large drinking glass taken and ground down, so as to have three flat sides, which answered all the purposes of a prism tolerably well. All these glasses mentioned above, are called by the common name of Lenses.

THE more obliquely a ray of light falls upon any one of these, as we said before, the greater will be the angle of incidence, and consequently greater will be the angle of refraction. If, therefore, the solar rays fall upon one of these glasses with a surface not quite flat, but irregular, it is very evident that the same rays will fall with different obliquities upon these different surfaces, and consequently be differently refracted, or bent, in their passage through the glasses. Let us illustrate this in every particular glass.

A ray

A ray of light A B C falling (see fig. 63) perpendicularly on a plain glass, is never refracted; but if it falls obliquely it will be refracted upon its entrance into the denser glassy medium, and be again refracted upon its exit from behind the glass into the air. It will alter its direction as it goes into the glass; but upon going out, it will resume the same direction with which it entered. Thus it will be refracted in the line B C, upon entering; and upon going out will be again refracted in the line C D.

If several rays of light fall together on a glass E D, convex on one side (see fig. 64) they will be differently refracted, in proportion to the obliquity with which each of them falls upon the surface. The middle ray, for instance, which passes perpendicularly through, will not be refracted at all, but go on straight forward. All the other rays, however, will suffer refraction. The ray

ray C E will be refracted upwards to F ; the ray A D will be refracted downwards to the same point. There they will cross, and then go onward, diverging or separating from each other for ever ; that which came from the bottom going upward, and that which came from the top downward. The figure we have given there is flat, but it must be supposed round, the glass being represented edgewise. If so, therefore, the collected bundle of rays, passing through the glass, unite and form a cone, or a figure like a candle extinguisher, the bottom of which is at the glass, and the point at F. This point, as we once before had occasion to mention, is called the focus of the glass. From a calculation in deep geometry we learn, that the distance from this point is always equal to the diameter of the circle which the glass would make if its convexity were continued.

WHEN the rays of the sun fall directly upon a glass D E (see fig. 65) equally convex on both sides, they will be refracted still more abruptly, and meet sooner in a point or principal focus at F. The distance of this focus is, we are informed by the same abstruse calculation, equal to the semi-diameter of the circle, which the convexity of the glass continued would make. Either this glass or the former, as they collect the rays of the sun into a point, will burn at that point, since the whole force of the rays is concentrated there. Their surprising power in this way we have had occasion to mention before. The broader the glass in these instruments, the greater will be its power.

As parallel rays, striking upon these glasses, are thus converged to a point, it must naturally follow, that when the rays, diffusing themselves from a point, as from a candle, strike one of these glasses, they will be refracted parallel.

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If, therefore, we place a candle at a focal distance from one or both of these glasses, as at *f*, its rays will, upon going through the glass, all run parallel to each other. If the candle be placed nearer the glass than its focal distance, the rays, after passing through the glass, will no longer run parallel, but separate or diverge: if it be placed further off, the rays will then strike the glass more parallel, and will therefore, upon passing through it, converge or unite at some distance behind the glass.

BUT it is very remarkable, that where these rays fall, as in the solar rays, they not only unite, but they also form an inverted picture of the flame of the candle, as may be seen on a paper placed at the meeting of the rays behind! How the image is inverted is easy to apprehend; for we observed above, that the upper rays, after refraction, were such as came from the under part of the luminous body; and that the under rays,

on the contrary, came from its top: so that the rays are turned up-side down, and so consequently is the image. It is very pleasing to view a picture of this kind thus formed, each ray preserving the colour it had in the luminous object, with the most imitative precision. The shadings of the little piece are far beyond the reach of art, and the design far more correct than that of the finest painter. We mention the candle as being an obvious luminary; but if any object whatsoever be placed at the proper distance from a convex glass, its picture will be in the same manner thrown behind, and may be received upon paper, or any other body whatsoever, in all its natural proportions and colourings. The nearer the natural object is to the refracting glass, the farther off will this picture be behind it; because, as we said before, the rays which form it do not then converge or unite, but at a great focal distance. The farther off the natural object is, the nearer will be
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the focal distance it makes, and consequently the nearer will be the picture behind the glass; for wherever the focus is, there will the perfect picture be. However, when the rays come from several objects at a moderate distance, they may be then considered as all parallel, and this difference of focus is then imperceptible.

To put what has been said in other words — As the rays of the sun may be all considered as falling parallel upon every glass of the convex kind, so they must always unite behind it in a focal point. As all the rays flowing from other objects are not always parallel, when placed too near the glass, they separate after refraction, and run off divergent; when placed at a proper distance, they unite or converge in a focal point, and there imprint a picture, if there be any thing properly placed to receive it, in which the natural figure

will be represented, its motions, its colours, and shadings.

THE whole foregoing theory may be demonstrated with a common reading-glass. If a candle is held so near it, as that the rays passing through shall strike the wainscot of the chamber with a bright spot, just as large as the glass itself, the candle is then at the focal distance; and rays, striking the glass divergently, are refracted through it, parallel to each other, neither spreading nor drawing together as they proceed. If the candle is held nearer than the focal distance, the rays will fall then more divergent upon the glass, and will consequently be refracted more divergent, so that they will form a very broad spot of light upon the wainscot. If the candle be placed at a much greater distance than the focus, the rays fall upon the glass more parallel, and consequently when they are refracted will tend to unite and converge behind the

the glass, and will form but a small speck of vivid light on the wainscot. This speck, if closely examined, will appear a perfect picture of the candle.

EVERY visible point, in any body whatsoever, may be considered as a candle sending forth its ray, which splits and *pencils* out into several other rays before it arrives at the eye. Each body is as if composed of an infinite number of splendid points or candles, each point with its own radiance, and diffusing itself on every side. Instead of one body, the eye in fact is impressed with thousands of radiant points sent out from that body, which being grouped at the bottom of the eye, imprint the picture of the object from whence they flow. Each point sends forth its ray.

Now, if, instead of candle light, we use that of the sun, by holding this glass opposite his beams, as these all strike the glass parallel to each other, they

will be united soon into a focus behind, and where they unite will burn with great fierceness. Suppose we adapt this glass, so as to fit an hole in the window-shutter of a darkened chamber, so as that no light shall come into the room but through the glass; then let us place a sheet of white paper behind it at the proper distance, we shall thus have a *camera obscura*; for a picture of every external object will pass through the glass, and be painted upon the paper in the most beautiful colours that imagination can conceive, and all the motions of those objects also. It is necessary, in this experiment, that the window should not be opposite the sun; for then we should see no image but that of his brightness: and yet it is necessary also, that while we make the experiment, the sun should shine and illuminate the objects strongly, which are to paint themselves within. Without this strong illumination, the rays will be sent so feebly from every object, that

that we shall have but a very faint picture, if any at all.

PAINTERS and architects often make use of a similar contrivance to take a draught of landfkips or buildings : their glafs is fixed in a box, and by means of a mirrour, on which the objects fall, they are reflected upon oiled paper properly placed, upon which the artist sketches his draught. With regard to the contours, or out-lines, which this picture gives, nothing can be more exact ; but, with regard to the fhading and colouring, the artist can expect but little affiftance from it : for, as the fun is every moment altering its fttuation, fo is the landfkipe every moment varying its fhade ; and fo fwift is this fucceffion of new fhade, that while the painter is copying one part of a fhade, the other part is loft, and a new fhade is thrown upon fome other object.

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IF such a glass be so fitted to an hole in a dark lantern, so that little pictures, painted in transparent colours on pieces of glass, may be passed successively along between the glass and the candle in the lantern, we shall thus have a magic lantern. The pictures, striking the glass very divergent, will be refracted very divergent also, and will be painted upon the wall of the chamber in all their colours, as large as we please to make them; for the farther the wall is from the glass, the more room will the rays have to diverge. To illuminate the little figures more strongly, another glass must be used, which may either reflect or refract the light of the candle upon them.

BUT of all the optical instruments that we know, those made by art are nothing to the natural one of the eye, which has its convex glasses, and differently refracting mediums, all adjusted in the most admirable order, while a fine tapestry is hung behind to receive the
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the image from without. But, to quit tawdry common-place observations, let us describe the *eye* itself, and trace Nature through her various operations in that wonderful piece of mechanisim.

CHAP.

C H A P. VI.

Of the Eye.

THE eye is nearly globular, as we may easily observe by the eyes of sheep or oxen when taken out of the head. But it is not perfectly round; for, if I may use the expression, it blisters out a little before, as at E, (see fig. 66.)

WE all know that the eye of an ox is composed of an external coat or skin, which, like a bladder filled with water, contains a fluid within it. This external coat is made up of three coats, one without the other, like the bark of a tree, which may be separated into three coverings; and the fluid within also is easily distinguished into three transparent humours of different densities,

ties; one of them as thin as water, the other like jelly, and the third as hard as gum arabic.

BUT first as to the three coats of the eye. When we take the eye of an ox from the head, we first find an outward fleshy skin almost covering the ball of the eye, which does not properly belong to it, but to the skull. It is not reckoned among the coats of the eye, although it makes what we call the white of the eye. Now then, this membrane being taken away, there are under it three proper coats belonging to the eye. The outward coat is called the *sclerotica*, a finer coat next this is called the *choroides*, and the most internal of all is the *retina*, which covers chiefly the internal back part of the eye. The outward coat, or *sclerotica*, is transparent, like horn, on the fore-part of the eye, and that part of it is therefore called the *cornea*, or horny-coat. The *cornea* is represented by D E C.

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cond coat, or *choroides*, does not line the *cornea*, as it does the other parts of the upper coat, but leaves a passage before for the light to enter, opening in a sort of mouth, which is gathered or expanded by little fibres, which open it or contract it, as running strings do the mouth of a purse. These fibres are called the *iris*, and may be seen through the transparent *cornea*, and they also give the denomination of colour to the eye. Whenever there comes too much light to the eye, the circular fibres of the *iris* contract the opening; whenever the light is rather wanted, the radial fibres of the *iris*, on every side, draw the hole more open. The little hole, which the *iris* thus contracts or dilates, is no other than the pupil or sight: that little black speck, which we see so shining in every eye, and which we know to be sometimes larger and sometimes less. The most internal coat is the *retina*: this lies at the back of the eye, and somewhat resembles a spider's web.

THE

THE coats of the eye being thus disposed, the fluid within is distinguished in the following manner. In the fore-part of the eye, just behind the *cornea*, lies a fine transparent fluid like water: it gives that protuberance to the eye on the fore-part, which was mentioned in the beginning, and fills up the cavity *mm* and *nn*. Farther backwards lies the crystalline humour *LL*, of the consistence of gum arabic, and pretty much shaped like a small horn-button mould: it stands with the most convex side backwards, and it is sometimes brought forward a little by fibres, called the Ciliary Circle, which go round its edges like a hoop. Hindmost of all the humours lies that called the Vitreous Humour, *KK*, of the consistence of a jelly, perfectly transparent, and in great quantity, filling all the back part of the eye. Now then, if we have a clear idea of the foregoing description, we must know, that the aqueous or watery humour lies foremost in the eye, that the
hard

hard cryſtalline humour ſtands farther back, by being placed behind the pupil, or hole of the eye, as we would fix a glaſs behind the hole of a window-ſhutter in a darkened room. Behind this is the vitreous humour, filling the whole backward apartment of the eye. If we expoſe a ſheep's eye in an hard froſt to one night's freezing, the next morning all the humours of the eye will be frozen, and we may with a ſharp knife cut the icy globe in two parts; by which means we ſhall have the moſt diſtinct view of the three humours, as they lie within their external covering.

IF by this time the reader has ſome idea of the ſtructure of the eye, the nature and manner of viſion will be eaſily conceived. As every point of every viſible object ſends forth rays that ſtrike the eye, let us ſuppoſe a viſual ray coming from the upper point of the external object A B. This, like all rays coming from a point, will diverge and ſeparate

as it goes along, and when it arrives at the *cornea* of the eye it will be spread upon its surface. Here, however, it is refracted by the aqueous humour, and thus it will be converged into a compass small enough to pass through the pupil, behind which it falls upon the crystalline humour where it is still more refracted; so that by the time it has passed thence it is nearly collected into a focal point, but still converging yet more as it proceeds through the vitreous humour, it will at last fall upon the back of the eye in a point: and thus there will be as many points formed on the back of the eye as there were visual rays sent from every part of the object; so that the whole picture of the object will be formed on the back part of the eye. The position, however, of the object will be inverted, the bottom rays being refracted uppermost and inversely, as we more than once had occasion to mention. The picture being thus formed, it is painted on the back part

of the eye, or the retina, which is only a fine expansion of the optic nerve, that is inserted towards the back part of the eye. This nerve runs to the brain, and by that means all its pictures are conveyed to the common sensory.

IT has been a subject of great inquiry to assign the cause how we come to see every object in its natural upright position, when we know it to be inverted on the organ of sensation. How when Nature draws the picture the wrong way, we so readily correct her errors and place it right again, even without being conscious of our rectitude. To solve this, some say that we certainly see every object the wrong way, but that our judgment first corrected the error, and habit corrects it in succession. To correct this error at first, demanded an effort of the mind; but constant custom at length grew a second nature, so that, in a short time, our corrections became mechanical and instantaneous.

stantaneous. Judgment corrects so often, that it forgets that it corrects at all. As the motion of a tradesman's arms are first acquired by study and art, after a time he becomes insensible of their exercise, and even in his very walk, they often, against his will, betray his profession; so, say they, we have *taught* our eyes the art of seeing differently from what they would in a state of nature.

THIS is but a weak way of accounting for the causes of things. According to them we are under continual deceptions; how then can we trust our judgements that what they tell us is not a deception? The truth is, if there be any real resemblance between things and our sensations; as the image is inverted in passing through the humours of the eye, why may it not as well be again inverted in its passage from the optic nerve to the brain, the picture on the eye is immaterial in this consideration; the picture on the brain or common sensory is

all that we should strive to discover, and that may, for ought we know, be upright enough ; reason does not contradict this, and every moment's experience confirms it.

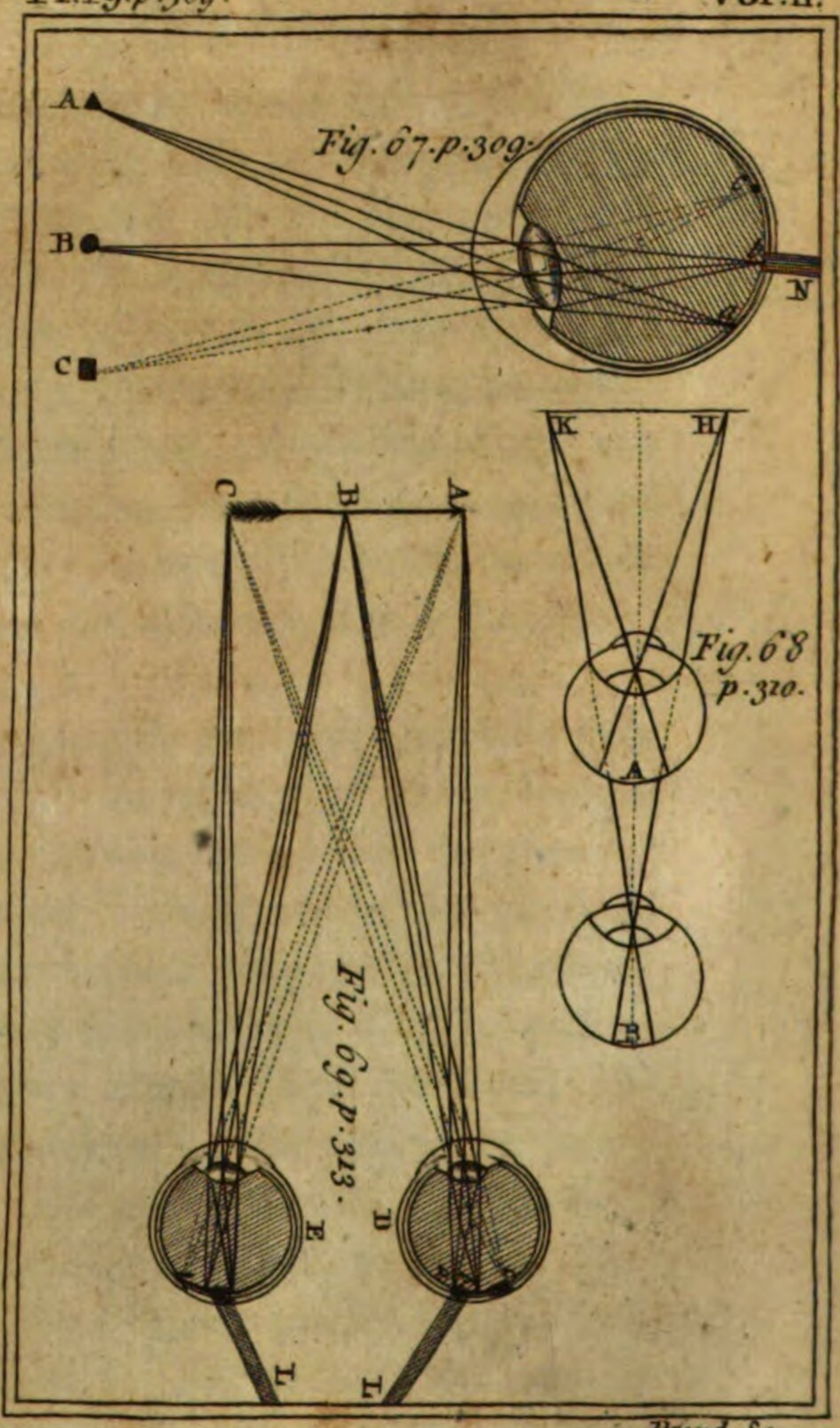
BUT to go on with the nature of vision. Though the three humours of the eye be requisite in seeing objects distinctly and at the proper distances, yet we can see tolerably well, even though one of them should be taken away, particularly if we assist the sight by glasses. It very often happens that the crystalline humour loses its transparency, and thus prevents the admission of the visual rays to the back parts of the eye. This disorder is called by the surgeons, a cataract. As we know that the crystalline humour stands edgeways behind the pupil, all then that we have to do, is to make it lie flat in the bottom of the eye, and it will no longer bar up the rays that come in at the pupil. A surgeon, therefore, takes a fine straight awl,

awl, and thrusting it through the coats of the eye, he depresses the crystalline into the bottom of the eye, and there leaves it. Or sometimes he cuts the coats of the eye, the crystalline and the aqueous humour burst out together; in some hours the wound closes, a new aqueous humour returns, and the eye continues to see, by the means of a glass, without its crystalline humour. This operation is called couching for the cataract. Cheselden once couched a boy who had been blind from his birth with a cataract. Being thus introduced, in a manner, to a new world, every object presented something to please, astonish, or terrify him. The most regular figures gave him the greatest pleasure, the darkest colours displeased, and even affrighted him. The first time he was restored, he thought he actually touched whatever he saw; but by degrees his experience corrected his numberless mistakes.

THE eye may be remedied when the crystalline humour only is faulty; but when

there happens to be a defect in the optic nerve L, which carries the image to the brain, then the disorder is almost ever incurable. It is called the *gutta serena*, a disorder in which the eye is, to all appearance, as capable of seeing as in the sound state; but, notwithstanding, the person remains for life in utter darkness. The nerve is insensible, and scarce any medicine can restore its lost sensations.

BUT though the optic nerve be thus the only conductor by which images are conveyed to the brain, yet there is an artery running through the midst of it, upon which, if the rays from an object happen to fall, there will be no picture whatsoever formed, and the object will remain unseen. That part of any image which falls upon the artery in the middle of the optic nerve, is entirely lost; for arteries have no sensibility, and consequently no power of perception. An easy experiment will show this. If we fix three black patches
A B C



Proud Sc.

A B C (see fig. 67) upon a white wall about as high as our eyes, each about a foot distance from each other, one to the right, one to the left, and one in the middle. Now, if the spectator places himself at a small distance before them, and shuts the right eye, then directing his left towards the patch C, he will see the patches A and C; but the middle patch B will be covered by the artery in his optic nerve, and will therefore disappear. Or, if he shuts his left eye, and directs the right towards A, he will see both A and C, but B will disappear; and if he directs his eye towards B, he will see both B and A, but not C. Whatever patch falls under the artery is unseen. This requires a little practice; but the spectator may soon become so expert, as by the direction of his eye to lose whatever patch he thinks proper. In our ordinary intercourse with visible objects, we are no way sensible of this defect in our sight; because we turn the visual parts

of the eye with so much rapidity upon the invisible part of the object. All losses that last but for an instant are imperceptible; each moment that the eyes twinkle we remain in utter darkness; the short duration of our want alleviates it.

THE nearer any object is to the eye, the larger is the angle by which it will appear in the eye, and therefore the greater will be the seeming magnitude of that body. Nothing can be more obvious. Suppose the object H K (see fig. 68) removed at a hundred yards distance, it will form an angle in the eye at A. At two hundred yards distance, the angle it makes will be twice as little in the eye at B. Thus to whatever moderate distance the object is removed, the angle it forms in the eye will be proportionably less, and therefore the object will be diminished in the same proportion. From this diminution of the magnitude of bodies we generally judge of their distance.

tance. I see a man upon the mountain side; he really appears to my eye an hundred times less than the child that stands near me. Instead of saying that the man is less than the child, I correct the information of the sense, and say that the child is much nearer me than the man. However, after all, it is, at present, with a great shew of reason disputed, whether these angles have much to do in vision; a child one yard distant from the eye appears under twice the angle of a tall man four yards from the eye; yet we know that painters, whose business is to imitate nature, make no such abrupt diminutions in perspective; their men, though ten yards behind, are larger than their children on the foreground of the canvas. The rule of angles therefore, is not observed in bodies very near, nor does it make any distinction in the distances of objects very remote. The celestial bodies seem all stuck upon the same starry vault, at one distance; the mountain's top, when
far

far removed into cloudy perspective, seems to enlarge rather than to diminish by its remoteness. The visual angle therefore, under which a body is seen, will only be justly diminished at moderately remote distances. Yet, after all, though the perspective diminution of objects give us an obscure idea of their distance, yet painters are obliged to call in another art to their aid, to give their figures the proper degree of remoteness; they spread over each a thick colouring of air; for the more remote the object, the more do its own colours seem lost in that of the intervening atmosphere. This is called *keeping*, for by this means every object in a picture seems to keep its proper distance from the rest.

WE have hitherto mentioned the effect of visible objects only upon one single eye, we need scarce repeat the proverb, that two eyes see better than one. In fact, by means of two we see more plainly, and are always better prepared,
in

in case of accidents. Opticians generally present us with a figure, by which they shew the method of two eyes seeing the same body at once (see fig. 69). In this both eyes are turned inwards, in order to take a view of an object placed at a small distance from them; so that they may be thus supposed to behold the same object only as one single body. This figure, and the theory also derived from it, seem to me erroneous. We cannot turn our eyes both inwards or both outwards, unless we squint. For instance, let a person try to throw both eyes at once on the point of his own nose, he will find himself utterly incapable of doing it. Nor do we, when turning both eyes towards the same object, see it single, as this figure would represent, but actually double. If we first observe an object with our right eye, and mind what part of the wainscot it corresponds with, then let us observe it with the left, and it will seem to correspond with a different part. Then let us observe it with both eyes at once,

once, and the object will seem in a situation between the two points with which it before corresponded. Thus we really see an image of the object to the right, and another to the left ; but our judgment determines it to be but one image between both. If we press the globe of either eye inwards with our finger, we shall make that eye squint ; and we shall see just in the manner as a man that squints naturally. But by this pressure we shall find, that if we turn to any object, we shall see two images instead of one ; whereas, the man that squints naturally, thinks he only sees one single image. Whence comes this difference ? The truth is, he sees two images as well as we ; but he has long so learned to bethink right, that he forgets he was ever wrong : the mistake is new to us, and therefore the error is obvious. All persons, how straight soever their eyes may be, see two images, just as a man who squints ; but like him, they bring their other senses to correct the errors of

of

of vision. I once saw a disorder where the judgment was too feeble to give laws to sensation. Almost every one of the senses brought the unhappy patient its erroneous information; but I could not avoid remarking, that his sight presented every object to him double.

C H A P. VII.

Of the Method of assisting Sight by Glasses.

ALMOST every eye is so framed as to be able to see distinctly at different distances rays coming from different parts of the object. To see objects distinctly, it is requisite that each ray should be diffused upon the *cornea*, and from thence be converged into a point, which will help to stipple or point out the image of the external object upon the back of the eye. On this union, or pointing of the rays upon the back of the eye, depends distinct vision ; for should they be united before they come there, or should the point where they would unite, lie farther back than the *retina*, it is evident that the ray, from each point of the external object, would thus take up too much room in the back of the eye, and mix with that next it, and that with another, and so all the rays would be
thus

thus mixed and blended together on the back of the eye, exhibiting together a very confused representation of the object without.

Now, the greater the distance from whence rays come, the more parallel do they fall upon the eye; whence, therefore, the image of near bodies will not converge in the eye so soon as the distant ones; when they come from a less distance they are more widely scattered. The eye then must have a power of adapting its form to the reception of bodies at different distances. That is, if it is to receive the image of distant objects whose rays come parallel and converge quickly, it must have a power of bringing the back-part of the eye more forward to meet the focus of the convergent rays. On the contrary, if the object be very near, as the visual rays will then converge very far back, the eye must have a power of lengthening its orbit, in order to let the rays fall at
a proper

a proper focal distance on the *retina* behind. All this is performed by means of six muscles which are inserted into the outward coat of the eye, which, like so many cords or pulleys, lengthen the eye-ball at pleasure. So that by their means, the eye which is globular, is sometimes lengthened nearly into the shape of an egg with the small end foremost. When the object to be seen is very near, the muscles act together, and lengthen the eye to make a long focal distance; when the object is remote, the eye resumes its natural form, and the focal points of the distant rays fall upon the *retina*.

YET, notwithstanding this contrivance of Nature to adapt our eyes to different objects at different distances, there are some eyes, in which, rays coming from distant objects, will not find a proper focus, and objects will be therefore confusedly seen; while there are others where the rays from near objects will,
by

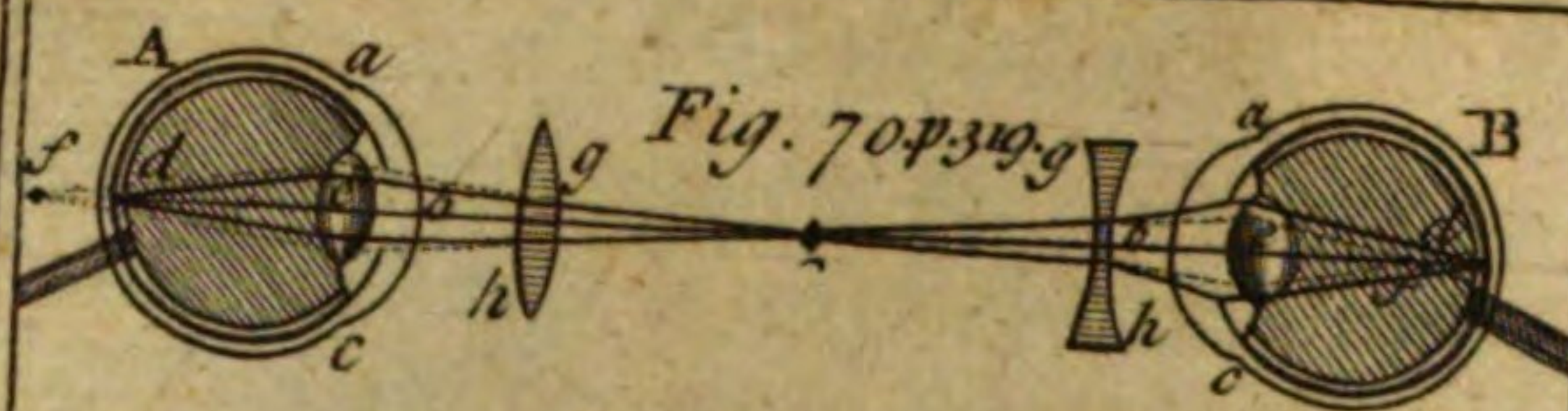


Fig. 71. p. 322.

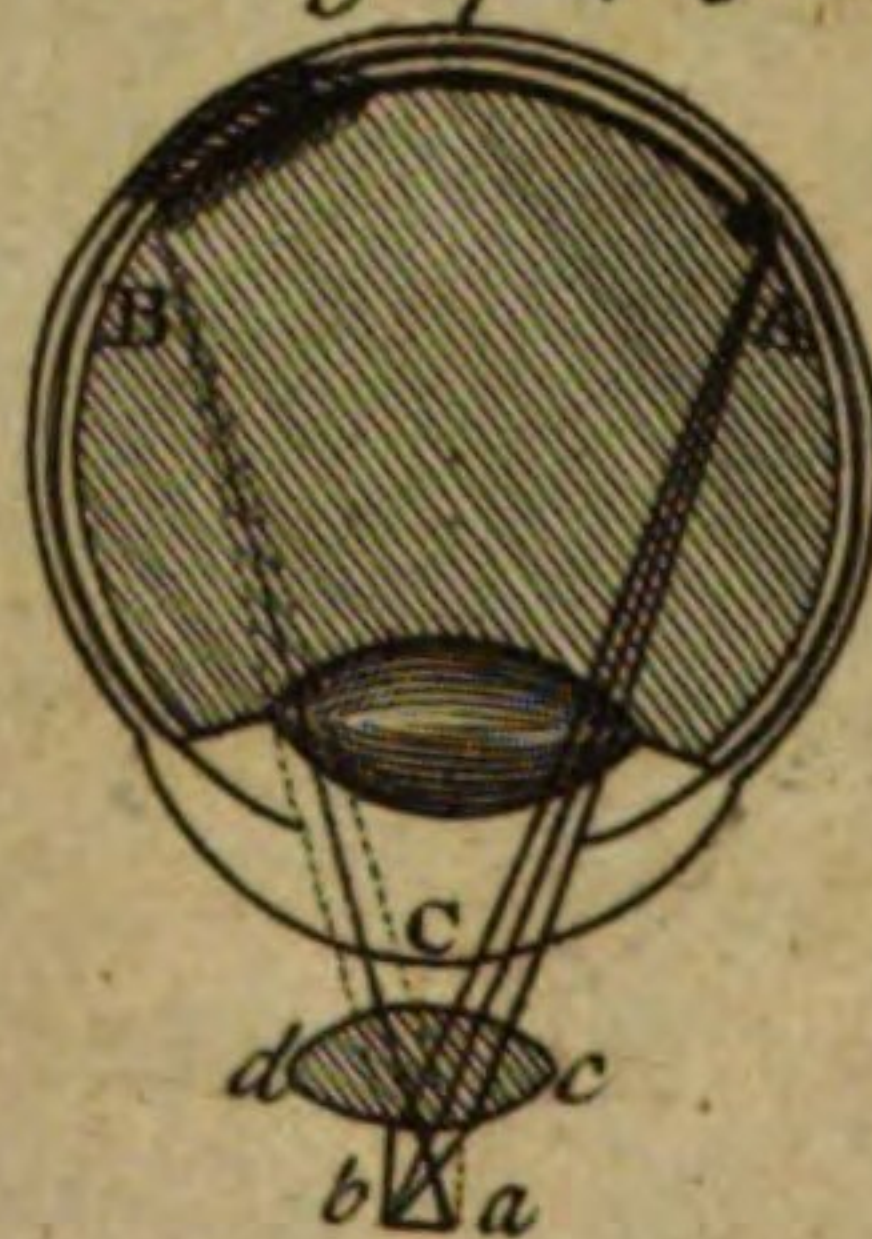
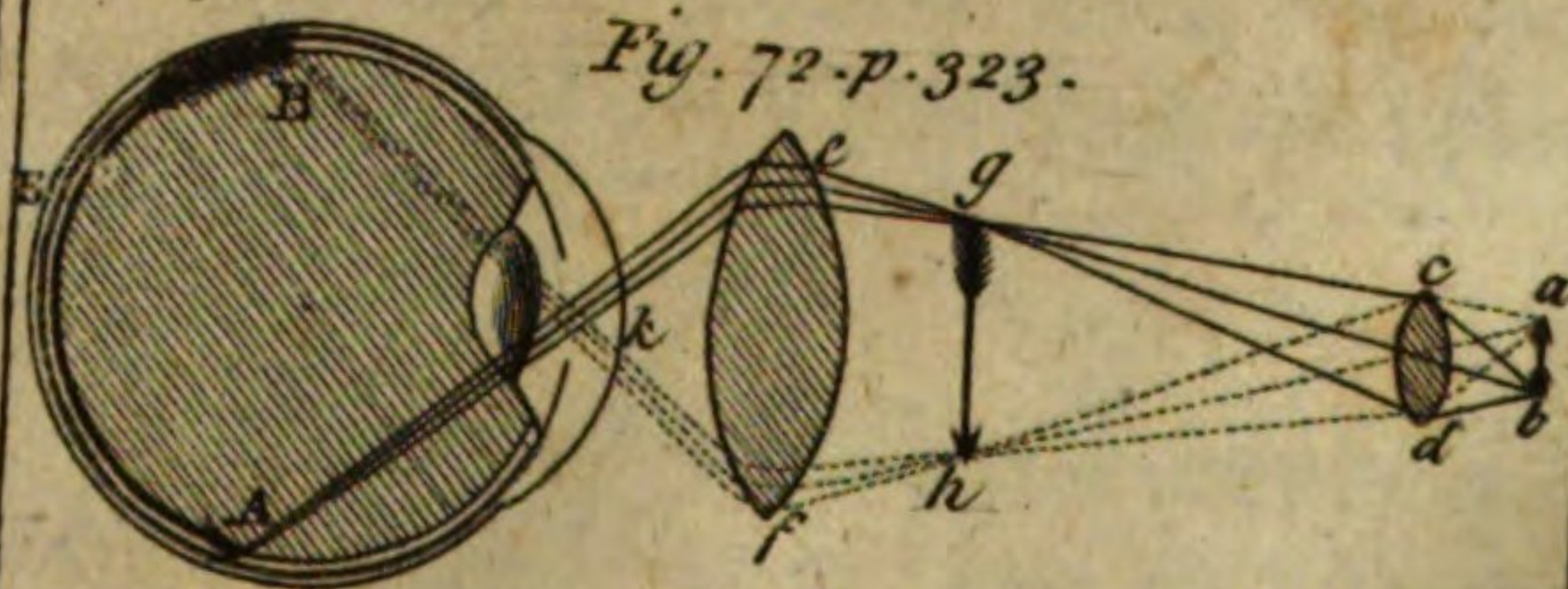


Fig. 72. p. 323.



by falling too far back into the eye, be equally confused. For if, in the first case, the *cornea*, or crystalline humour of the eye, be very convex, as in the eye B (see fig. 70) it will refract the rays too soon for distinct vision. For the rays that enter it from the object C, will be converged to a focus much too soon, and before they come to the *retina* at *f*. Persons thus affected, are said to be near-sighted, that is, they can see objects near the eye whose rays enter very divergent, with minute precision; but if the objects are removed at any considerable distance, they become confused and indistinct. If the ball of the eye has been long kept in a lengthened position by regarding very minute objects, it will, at length, assume this constrained form, and the person will become near sighted from the elliptical figure of his eye. Thus we see several persons become short sighted, when the nature of their employments obliges them to be conversant with the smallest subjects, as

miniature painters, virtuosi, and watch-makers. This inconvenience is remedied by using a concave glass, which always causes the rays to diverge; so that when they are made to fall diverging upon the eye, the focal distance is removed to the proper place, and is just upon the *retina*.

ON the other hand, there are eyes that require the use of convex glasses to make them see objects distinctly. For if the *cornea abc*, or crystalline humour be too flat, as is usually the case with the aged, they will not refract the rays so soon, wherefore their focus would fall behind the *retina*, and thus cause an indistinct impression. This infirmity is remedied by using a convex glass, which converges the rays before they come to the eye, and throws them, thus converging, upon the flat *cornea*, which, thus assisted, throws them exactly to the focal distance.

BUT

BUT there are other glasses which we now come to explain. The microscope, which magnifies small bodies to such immense bulks, is an instrument of infinite use to philosophy, since by it a new world is opened to the eye, of which mankind before never even suspected the existence. Of all those who have made microscopical discoveries, Leeuwenhoek deserves the first place; his researches were generally guided by sensible theory, and not diffused at random throughout all nature. He made many microscopical discoveries which have been since found true by repeated observation; he has made others, which we have adopted barely upon his authority; for neither our eyes nor our glasses are capable of arriving at a clear view of their minuteness. He left his microscopes to the Royal Society; we have since made others that magnify many degrees beyond them; yet for all this, our discoveries fall short of his observations. Long habit probably taught him better

arts of adapting his instruments, and fitted his eye more properly to them. The nearer any body is to the eye, the larger the angle it will be seen under; but then if placed too near the naked eye, the image will be confused and irregular. The microscope remedies this defect; it brings the object close to the eye, and yet does not hinder distinct vision.

THE common single microscope (see fig. 71) is only a small and very convex glass, as *c d*. The object to be magnified is placed at its focal distance, and the eye is to be at the same distance on the other side. The rays flowing from every point of the object run parallel after refraction, and spread themselves upon the *cornea*. From thence they are converged into as many different points on the *retina*, forming one large distinct picture. Large, for the object being very near is seen at a great angle; distinct, for the object's rays fall parallel upon

upon the *cornea*. If we would know mathematically, how much a glass of this kind magnifies the object, geometicians shew that we must first find out the focal distance of the glass, that we must next try at what distance we can, with the naked eye, view the same object distinctly. Divide this last distance by the former, and the *quotient* will be the body's apparent increase.

THE double, or compound microscope (see fig. 72) consists of an object glass *cd*, and an eye glass *ef*; the object to be magnified is placed at something more than the focal distance, by which means the rays converge after passing through it, and form the picture of the object a little before the eye-glass *ef*, and if it be properly placed, the picture should be exactly in its focus. The rays diverging from this picture fall upon the eye glass, where they again suffer refraction and pass on parallel to the eye, and will then be converged upon the *retina*,

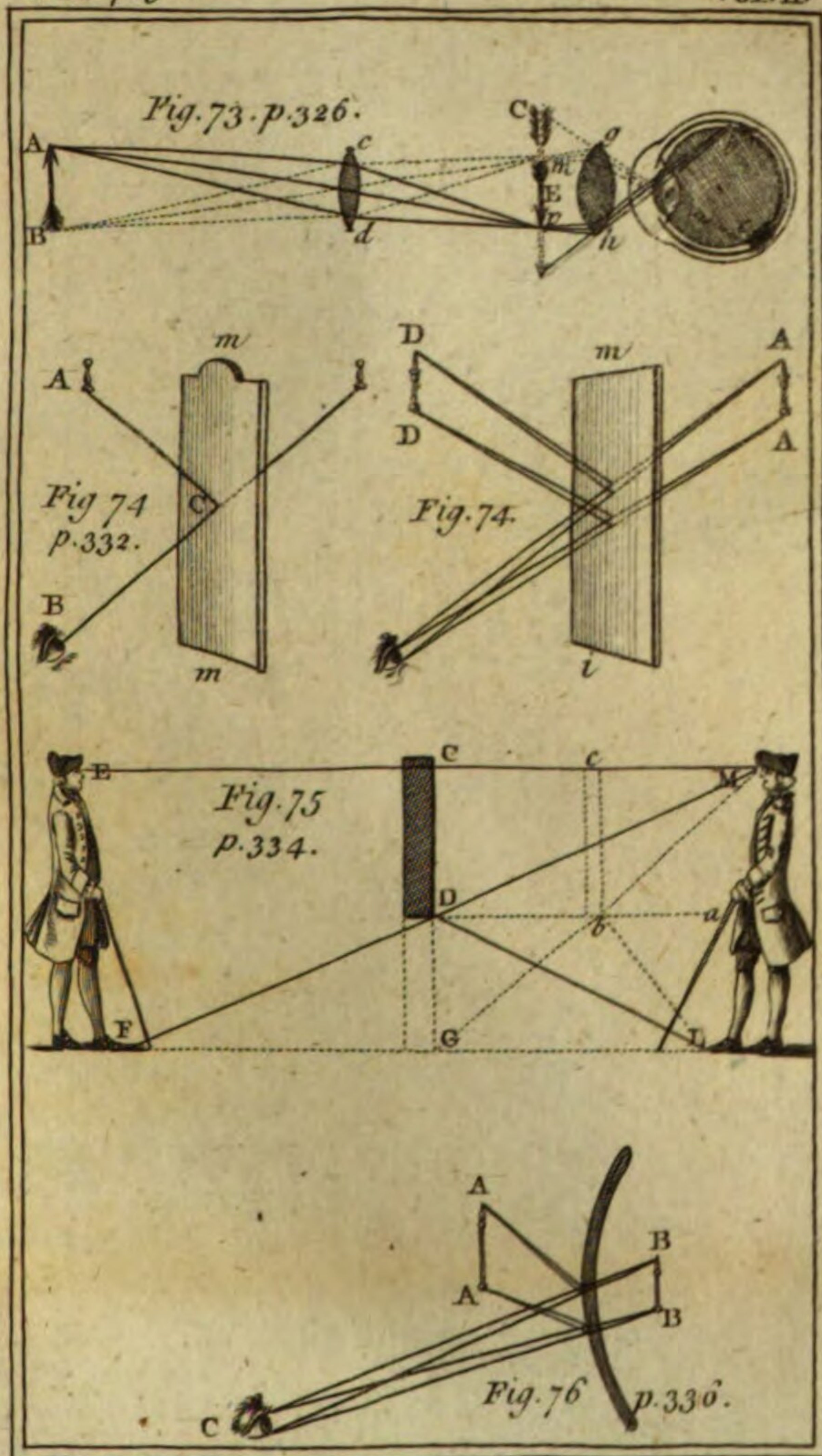
and form a large inverted image AB . The magnifying power of this microscope is as follows. Suppose the image $g h$ to be six times the distance of the object $a b$ from the object-glass $c d$, if so, it will be six times greater; this image may be seen distinctly, if placed within an inch of the eye-glass, whereas, the naked eye could not see it distinctly but at six inches distance; consequently it will be viewed under an angle six times greater still. So that it is increased six times six, which make thirty-six times. Its diameter will be thus magnified; its whole surface will be therefore increased by the square of the diameter, that is 1296 times.

Thus we see, by adding one glass, how much the surface of the minute object is enlarged; a third and a fourth glass, if added, would magnify it still more; but this addition of new glasses is absolutely precluded, because the more the glasses are increased, the more must
the

the light be diminished, and the darker will the object appear, till at last it be involved in utter obscurity. Mathematical instrument-makers have contrived various ways of making microscopes, and have given to each a peculiar name. There are catadioptric microscopes, solar microscopes, reflecting microscopes, and so forth; the description of but a part of these might occupy volumes, and the perusal might be of advantage to mathematical instrument makers.

WHATEVER microscopes perform upon minute bodies, very near; telescopes perform upon great bodies very remote; namely, they enlarge the angle in the eye under which the bodies are seen; and thus, by making them very large, they make them appear very near; the only difference is, that in the microscope, the focus of the glasses is adapted to the inspection of bodies very near; in the telescope, to such as are more remote. Suppose a distant object

at A B (see fig. 73), its rays come nearly parallel, and fall upon the convex glass $c d$; through this they will converge in points, and form the object E at their focus. But it is usually so contrived, that this focus is also the focus of the other convex glass of the tube. The rays of each pencil, therefore, will now diverge before they strike this glass, and will go through it parallel; but the pencils all together will cross in its focus on the other side, as at e , and the pupil of the eye being in this focus, the image will be viewed through the glass, under the angle $g e h$, so that the object will seem at E under the angle $D e C$. This telescope inverts the image, and therefore is only proper for viewing such bodies, as it is immaterial in what position they appear, as the sun, the fixed stars, &c. By adding two glasses more, the image may be seen upright. The magnifying power of this telescope is found by dividing the focal distance of the object glass, by the focal distance



Proud Sculp.

distance of the eye-glass, and the *quotient* expresses the magnifying power.

IT is not the design of the present elementary system, to exhibit long or accurate accounts of the whole philosophical apparatus ; the variety of telescopes is still greater than that of microscopes. The art of using these, or of understanding their construction thoroughly, is best learned from the artificers whose only business is to make them. Telescopes have received some improvements since the beginning of this century. Those they have received from Mr. Dollond, a mathematical instrument-maker, deserve to be mentioned. By increasing the number of glasses in the refracting telescope, he has made an instrument of this kind, but three feet long, magnify the object as much as an ordinary telescope of ten. It was long thought, and even demonstration had been brought to prove, that refracting telescopes were
incapable

incapable of farther improvement by the addition of a greater number of glasses. It was said, that some rays of light were more refracted in passing through glasses than other rays; so that numerous glasses would permit only the least refrangible rays to pass on through them all to the eye; and these rays which had been thus strong enough to get through, being but few in number, and all of one colour, they would imprint no picture. Dollond, however, disregarding the theory, tried the experiment of adding more glasses, and then theorists began to say, that light was not so very refrangible. It is remarkable enough, that the members of the academy of Petersburg, proposed the improvement of the refracting telescope to the learned, as a subject for the year's prize, the very year Dollond made this discovery. Dollond's improvement was yet unknown. Another received the reward, who asserted that the proposed improvement was impossible.

C H A P. VIII.

Of Catoptrics, or of objects seen by being reflected from polished surfaces.

AFTER having, as concisely as possible, shewn the various wonders of vision, why remote bodies appear small, why glasses seemingly alter their distance and magnitudes; after having shewn how the eye itself is an optical machine of the finest contrivance, capable at once of lengthening itself for distant view, and shortening for microscopic vision; yet still new wonders remain behind. How a looking-glass comes to reflect images, without their touching it; how the whole figure of a man six feet high shall be seen in a glass not above three feet? How when we look at some polished surfaces, as a watch case, for instance, a man's face seems not bigger than his nail? While, if we look on other surfaces, the face shall be of gigantic

gantic size ; these are all wonders that the curious would wish to understand, and the inexperienced to examine.

BEFORE Newton expanded nature to our view, it was supposed that every ray of light which bodies reflected, rebounded from their surfaces, as we see a marble bound when struck upon the pavement. Newton, however, taught mankind, that rays of light never touch the bodies from whence they are reflected; but that every ray, when it comes within a certain distance of the body, either passes entirely through, or is again struck back, as we see filings of steel when brought near to the loadstone. However polished the surface of the smoothest object may seem to our sight and touch, yet it is, in fact, one continued assemblage of inequalities. To us these inequalities appear small, but if compared with the smallness of light, they are as mountains. From the surface of such, therefore, it cannot be supposed

posed that rays will be reflected with that uniformity we usually observe; or that we could ever see an image of ourselves completely reflected; for unequal surfaces must make unequal and scattered reflections. "If light," says Newton, "were reflected by striking on the solid parts of the glass, it would be scattered as much by the most polished glass as the roughest." We must be obliged to allow, therefore, that it is reflected before it arrives at the surface, and that the whole body, and not any single point, drives it back; all the parts oppose their united repelling power, to meet the incurfive rays, and drive them back with uniformity.

LET us, however, for a short time, suppose that every reflected ray strikes against the body, and rebounds from it to the spectator's eye, like a tennis ball to the racket of a player. Now, whatever was the direction in which the ray struck the body, it will rebound with a contrary direction.

direction. If I strike an ivory elastic ball against the pavement, whatever force I impressed upon it, it will restore itself with a contrary force; and whatever direction I gave it, it will rebound in a contrary direction. If I strike it perpendicularly down, it will rise perpendicularly; if I strike it in an oblique direction, it will mount obliquely the other way. This is necessarily the result of its elastic quality. A ray of light may be considered as an elastic body, and whatever be the angle of its incidence upon the plain surface, the angle of its reflection will be similar. The line A C (see fig. 74) is the line of incidence, the line C B is the line of reflection, and these form equal angles on the surface of the polished mirror; so that all the rays coming from the object, and falling upon the mirror at C, will strike the eye at B, and the reflected image will thus become visible. But now a difficulty remains. How comes it then, that we do not see the
body

body at C, since it is there that all its rays fall; and why do we see it deep within, or behind the mirrour, at D? This is answered thus; no object can be seen that does not lie in a straight line from the eye, or, at least, appear to do so. The body A, therefore, when it comes reflected to the eye, will appear to lie in the straight line B D, which, since the angle of incidence is equal to that of reflection, will be exactly in the two lines A C and A B. The rays, therefore, going from A to C, will be seen at D, and consequently, so will the picture. For, as the rays have diverged in going from the object at A A, and diffused themselves upon the surface of the glass, they will be again converged into an equal focus, by the time they arrive at D D, and they will therefore paint the object at D D.

FROM hence we may learn, that if a man sees his whole image in a plain looking-glass, the part of the glass that

reflects his image, is but one half as long and one half as broad as the man. For the image is seen, under an angle, as large as the life; the reflecting mirror is exactly half-way between the image and the eye, and therefore must make but an angle half as large as the image, or in other words, it is just half as large as the image which is of the same size with the man. Thus the man *AB* (see fig. 75) will see the whole of his own image in the glass *CD*, which is but half as large as himself. His eye, at *A*, will see the eye of the image at an equal distance behind the glass at *E*. His foot at *B* will send its ray to *D*; this will be reflected at an equal angle, and the ray will therefore go in the direction of *FDA*; so that the man will see his foot at *F*. That is, he will see his whole figure *EF*. But suppose his foot was lower than *B* at *L*, then he could not see it; for the ray *L* striking the glass at *D*, would be reflected with an equal angle up to *M*, far above the man's eye, and
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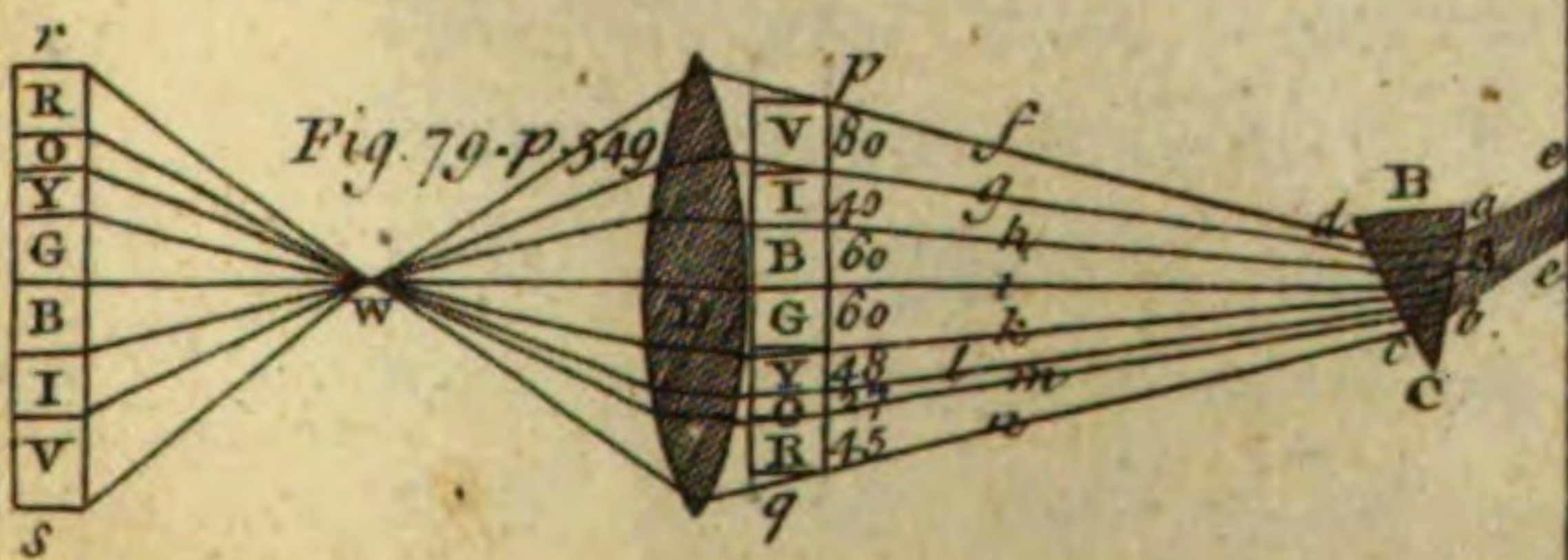
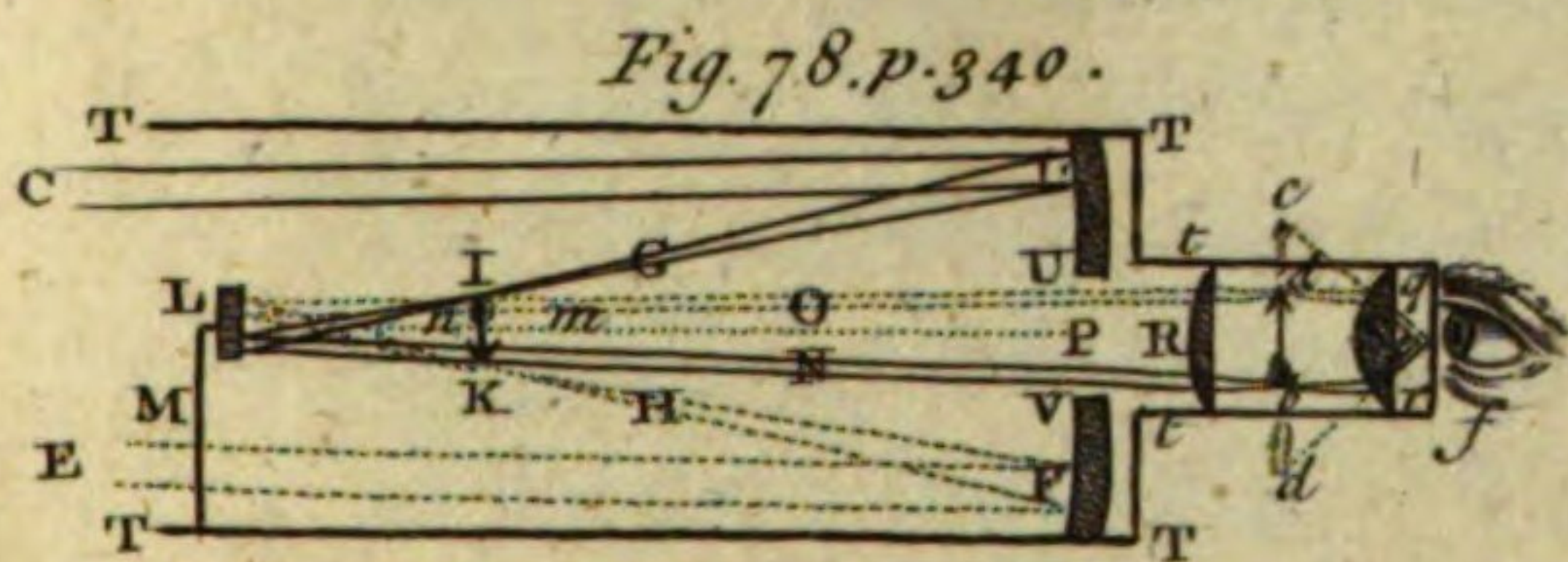
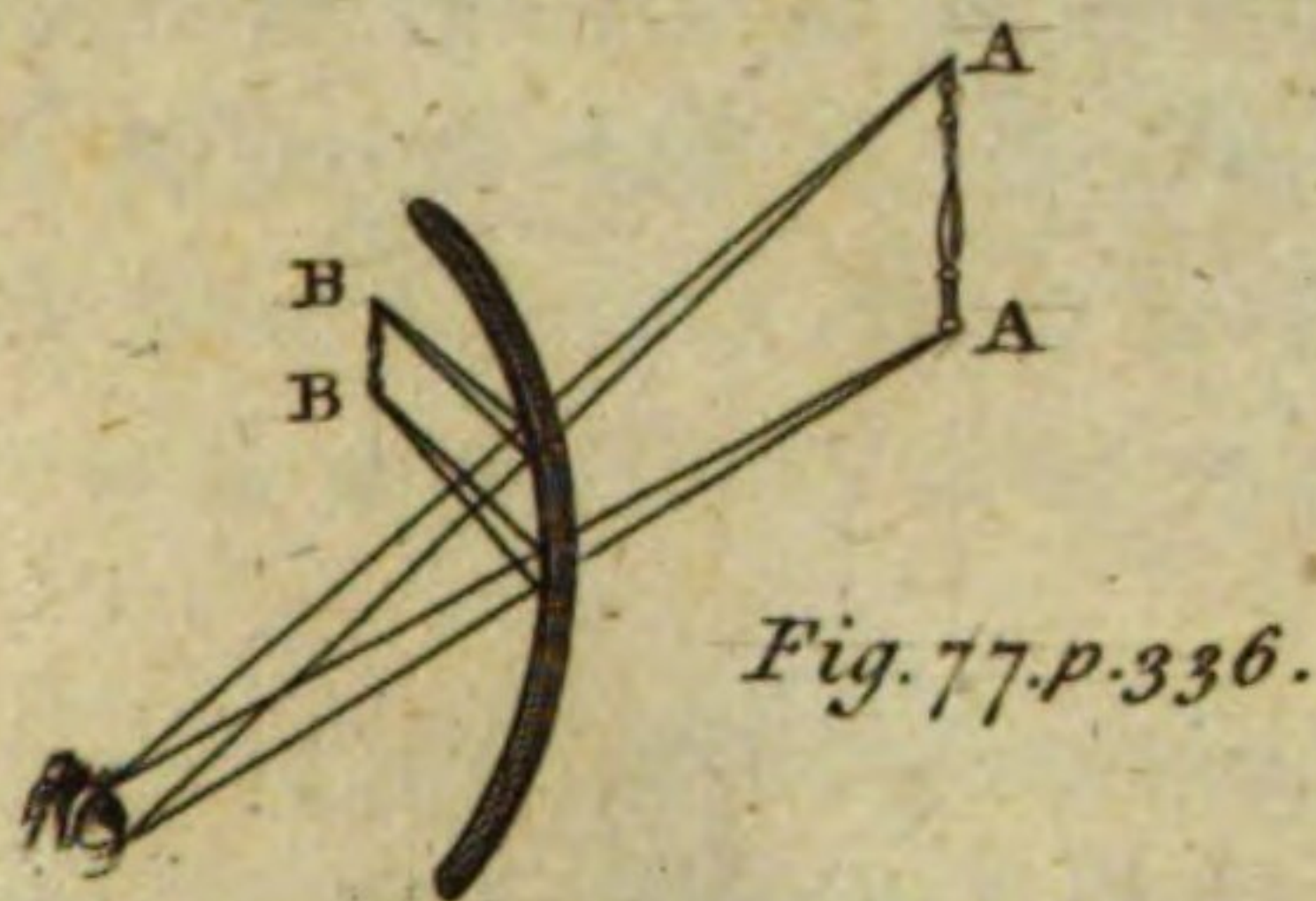
consequently out of his sight. In the same manner as he advances or retires, he will still see his own image, if all the lines of reflection come to his eye; but if they rise above it, like D M, or fall below it, that part of the object, to him, will be invisible, though another spectator at M may see his feet at L, which he himself cannot see.

THUS plain mirrours reflect, not only the object, but the distance also, and that exactly in its natural dimensions; but it is otherwise with regard to convex mirrours, such, for instance, as a watch-case, which diminish; or concave mirrours, which, on the contrary, magnify it. As to convex mirrours, the nearer we approach them, the more the image starts back; in the case of concave, as we draw near them, the image seems to step forward, beyond the glass, to meet us.

To show first, how images are lessened in the convex mirrour, we must still

repeat the former rule, that the angle of reflection is ever equal to the angle of incidence. Carrying this in our memory, let us suppose (fig. 76) an object A A is reflected by a convex glass, to the eye, at C. Let us consider, at what angles each pencil of rays, from the object, will fall upon this convex surface. It is certain, that each angle which they make with it, will be more acute than if the mirror's surface were perfectly flat. If so, after reflection, the reflected rays being supposed to pass onward to B, they will be converged much sooner from acute, than if they came from large angles; and the object B B will therefore appear more near and smaller than the life.

On the other hand, with regard to concave mirrors, an object must appear in them larger than the life, if it be placed moderately near (see fig. 77). For the pencil of rays B B falling at larger angles upon the concave surface, if they are reflected; they will not converge



verge so soon, and not till they apparently come to the greater distance A A. They will therefore, be seen at A A. But A A is larger and more distant from the glass than the real object B B, and therefore it is apparently magnified.

As the real principles of catoptrics are perfectly mathematical, and can be known only by those who are versed in deep geometry; it would be vain to attempt leading the reader farther into this subject, as every step onward would be found to increase the gloom. The principles of this science, particularly with regard to the places where objects are seen in mirrors, are yet in dispute among mathematicians, and hitherto undecided. Newton acknowledges the determination of the apparent place of an object, seen in a concave mirror, to be the most difficult part of all mathematics. His words are, *Puncti illius accurata determinatio, problema solutu difficillimum præbebit, nisi hypothese alicui saltem veri-*

simili, si non accurate veræ, nitatur assertio.

The solutions of such problems will be immensely difficult, unless we take the probability of conjecture to ground assertion on.

THERE are several amusing optical deceptions which are effected by a proper combination of plain or convex mirrors. We all know, that if a man stands with his face opposite a looking-glass, and with his back to another, he will see his figure many times reflected. If an hexagon chamber, (one with six sides) be so contrived as to have light admitted, in sufficient abundance, from the top, and a large glass on every side, a man standing in this chamber, will see himself multiplied into a seeming crowd. The effect is still more pleasing by candle light.

LET there be a box of six sides, and divide its inside by as many little partitions running from each corner, which
will

will all consequently unite in the middle. Line each partition with looking glasses, and let there be an hole made on every side of the box to look through. Cover these holes with plain glass, and cover the top of the machine, thus prepared, with fine oiled parchment, and the catoptric box is made. Whatever object we place upon the side or sides, at which we look in, it will be multiplied in the most pleasing manner, and by turning different sides, a variety of prospects may be thus offered to the view, each seemingly twenty times larger than the capacity of the machine we look through.

IN another box, if we use a convex glass, such as we usually read with, at a hole on the side of the box, and place a looking glass in its focus, in such a manner, that while the focus falls upon the mirror, the mirror at the same time reflects objects or pictures below; this will magnify those pictures very much, and place them seemingly at a great

distance

distance from the eye. These may amuse the youthful ; but there have been catoptric instruments formed for the amusement of philosophers. The reflecting telescope is among the number. This instrument was first invented by Newton, who saw the inconvenience of using very long refracting telescopes, and therefore substituted reflectors. He gave directions for making one of six inches long, which was found to magnify objects as much as a common refractor of four feet. If any reader desires to know the construction of this instrument, he shall have it from Mr. Ferguson's description, which is the plainest that I have met with.

“AT the bottom of the great tube T T T T (see fig. 78) is placed a large concave mirror D U V F, whose principal focus is at *m* ; and in the middle of this mirror is a round hole P, opposite to which is placed the small mirror L concave toward the great one, and

and so fixed to a strong wire M, that it may be removed further from the great mirrour, or nearer to it, by means of a long screw on the outside of the tube, keeping its axis still in the same line P *m n* with that of the great one. Now, since in viewing a very remote object, we can scarce see a point of it, but what is, at least, as broad as the great mirrour; we may consider the rays of each pencil which flow from every point of the object, to be parallel to each other, and to cover the whole reflecting surface D U V F. But to avoid confusion in the figure, we shall only draw two rays of a pencil flowing from each extremity of the object into the great tube, and trace their progress through all their reflections and refractions to the eye *f* at the end of the small tube *t t*, which is joined to the great one.

“LET us then suppose the object A B to be at such a distance, that the rays C may flow from its lower extre-

mity B, and the rays E from its upper extremity A; then the rays C falling parallel upon the great mirrour at D, will be thence reflected converging in the direction D G, and by crossing at I in the principal focus of the mirrour, they will form the upper extremity I of the inverted image I K similar to the lower extremity B of the object A B, and passing on to the concave mirrour L, (whose focus is at *n*) they will fall upon it at *g*, and be from thence reflected, converging in the direction *g* N, because *g m* is shorter than *g n*, and passing through the hole P in the large mirrour, they would meet somewhere about *r*, and form the lower extremity *b* of the erect image *a b* similar to the lower extremity B of the object A B. But by passing through the plano-convex glass R in their way, they form that extremity of the image at *b*. In like manner, the rays E, which come from the top of the object A B, and fall parallel upon the great mirrour at F, are thence reflected converging to its focus, where they

they form the lower extremity *K* of the inverted image *IK* similar to the upper extremity *A* of the object *AB*, and thence passing on to the small mirror *L*, and falling upon it at *b*, they are thence reflected in the converging state *bo*, and going on through the hole *P* of the great mirror, they would meet somewhere about *q*, and form there the upper extremity *a* of the erect image *ab* similar to the upper extremity *A* of the object *AB*. But by passing through the convex glass *R* in their way, they meet and cross sooner, as at *a*, where that point of the erect image is formed. The like being understood of all those rays which flow from the intermediate points of the object between *A* and *B*, and enter the tube *TT*, all the intermediate points of the image between *a* and *b* will be formed. And the rays passing on from the image through the eye-glass *S*, and through a small hole *e* in the end of the lesser tube *tt*, they enter the eye *f*, which sees the image *ab* by means of the large eye-glass under

under the large angle ced , and magnified in length under that angle from c to d .

“ In the best reflecting telescopes, the focus of the small mirrour is never coincident with the focus m of the great one, where the first image IK is formed, but a little beyond it (with respect to the eye) as at n . The consequence of which is, that the rays of the pencils will not be parallel after reflection from the small mirrour, but converge so as to meet in points about q, e, r , where they would form a larger upright image than ab , if the glafs R were not in their way; and this image might be viewed by means of a single eye-glafs properly placed between the image and the eye; but then the field of view would be less, and consequently not so pleasant, for which reason the glafs R is still retained to enlarge the scope or area of the field.

To find the magnifying power of this telescope, multiply the focal distance of
the

the great mirrour by the distance of the small mirrour from the image next the eye, and multiply the focal distance of the small mirrour by the focal distance of the eye-glass; then divide the product of the former multiplication by that of the latter, and the quotient will express the magnifying power."

C H A P IX.

Of Colours.

WE have hitherto considered light as a body uncompounded and of parts resembling each other; but we are now going to examine its texture more closely: we shall now see that this fluid, though so simple to all appearance, is made up of very different particles; that it is composed of different coloured tints, and that from the nature of this composition arises that charming variety of shades which paint the face of Nature,

WHATEVER pleasures we derive from the beauty of colouring is owing to the different rays of light alone; for the objects themselves have no difference in this respect at all: the blushing beauties of the rose, or the modest blue of the violet, are not in the flowers themselves, but in the light that adorns them: odour, softness,

ness, and beauty of figure are their own ; but it is light alone that dresses them up in those robes which shame the monarch's glory. Take away all light and their colour will vanish ; let but a portion of light be permitted to shine upon them, and their colours will be changed. But though the colours be in the light, and not in the objects, yet it is in our power to alter them at pleasure ; we have only to change the surface of the object, and light instantly gives it another colouring. Thus in every circumstance we at best resemble those servants of painters who prepare the frame or stretch the canvas, but it is light alone that always holds the pencil.

THERE is a common experiment, and easily performed, to prove that the colours are not in the objects themselves, but in the rays of light that fall upon them ; and that if the nature of light be altered, the colours also will receive alterations : Let a pint of common spirits,
the

the cheapest will answer as well as the best, a pint of malt spirits then, be poured into a soop-dish, and then set on fire: as it begins to blaze, let the spectators stand round the table, and let one of them throw an handful of salt into the burning spirits, still keeping it stirring with a spoon. Let several handfuls of salt be thus successively thrown in; the spectators will see each other frightfully changed, their colours being altered into a ghastly blackness. Were the solar flame of the same nature with that of this composition, we should have no other colours in nature but such as those produced by the experiment.

NATURALISTS were formerly of opinion that the solar light was simple and uniform, without any difference or variety in its parts, and that the different colours of objects were made by refraction, reflexion, or shadows. But Newton taught them the errors of their former opinions; he shewed them to dissect
a single

a single ray of light with the minutest precision, and demonstrated that every ray was itself a composition of several rays, all of different colours, each of which when separate held to its own nature, simple and unchanged by every experiment that could be tried upon it.

To prove all this, it was necessary first to find out a method of splitting a single ray of light into the several rays of which it was composed, and this was effected by means of the prism, or a three square glass already described. Let the sun shine into a dark room through a small hole as at *ee* in a window-shutter (See fig. 79.) and place a prism *BC*, which we see endways in the figure, in the beam of rays *A*, in such a manner, that the rays may fall obliquely on one of the sides *abc* of the prism. We shall then see the rays that pass through the prism struck upon the opposite wall, ranged one above the other, violet, indigo, blue, green, yellow, orange, red. The
range

range will be beautiful, and the colours so bright as to exceed the power of art to equal. In this manner then is the solar beam separated into the colours of which it is in nature composed; and one ray consists of many rays, each different in its colour, and darting forward from the great luminary with different force. The red ray, for instance, goes forward more forcibly than any of the rest, and is therefore least refracted or bent out of its rectilinear course, but falls upon the wall almost in a straight line at R. In proportion as each succeeding ray has less force, it is driven more out of its rectilinear direction, till at the violet it feebly paints itself upon the highest part of the picture.

THUS we see that in nature the brightest colours drive forward from the sun with the greatest force; and what we find true by experiment, is confirmed by our sensations. The brightest colours strike our eyes with the greatest force; the

the red makes strong impressions, the orange is not so forceful; the colours strike us less vividly in succession till we come to the violet, which approaches very near to black, and gives us a faint idea of darkness. For this reason it is, that when the eye is very weak, a scarlet colour becomes insupportable, its impressions are too powerful, and next to the solar beam itself, dazzles and disturbs the organ. Surgeons in this case generally prescribe a black object to be placed before the eye, as a piece of black silk, for instance; but violet is very near approaching to blackness, so that that would do almost as well.

WE now therefore may conclude, that a single ray of light, which before separation seemed to be of an uniform white appearance, is composed of a bundle of no less than seven different rays, and that when an object reflects them all, it then appears white. On the contrary, if the object sends back no rays to our eye, it

then appears black, which is nothing more than the privation of all colour. If we could find an object perfectly black, such a body would be to us perfectly invisible; such however is not to be found in nature; and painters in drawing black objects are forced to heighten all the ground with white: and it is so in nature; the black which we see is an assemblage of different colours, and faintly reflecting rays of almost every kind. Should it be doubted that white is but the assemblage of all the colours of the prism united, numberless experiments can be easily brought to confirm it. The rays, when divided by a prism, if they be again united by a common convex glass, will throw a bright spot of white upon the same paper, where before they separately painted the beautiful prismatic variety. If a round board be painted with colours, imitating those from the prism, and if it be then turned swiftly with a circular motion, so as that the eye cannot have time to view any one of the colours distinctly,

distinctly; as it takes in the whole assemblage together, the figures on the board will reflect every colour, and appear white or nearly approaching to whiteness.

THESE colours, reflected by the prism, are not only the most beautiful in nature, but also each in itself continues separate and unalterable. When one of those primitive rays has been separated from the rest, nothing can change its colour. Send it through another prism, expose it in the eye of a burning-glass, yet still its colour continues unaltered; the red ray will preserve its crimson, and the violet its purple beauty; whatever object falls under any of them, soon gives up its own colour, though never so vivid, to assume that of the prismatic ray. Place a thread of scarlet silk under the violet-making ray, the ray continues unaltered, but the silk instantly becomes purple. Place an object that is blue under a yellow ray, the object immediately assumes the radial colour. In short, no art can

alter the colour of a separated ray; it gives its tint to every object, but will assume none from any; neither reflexion, refraction, nor any other means can make it forego its natural hue; like gold, it may be tried by every experiment, but it will still come forth the same.

IN whatever manner we consider the colour of a single prismatic ray, we shall have new cause to admire the beauties of nature. Whatever compositions of colouring we form, if examined with a microscope, they will appear a rude heap of different colours unequally mixed. If by joining, for instance, a blue with a yellow, we make the common green, it will appear to the naked eye moderately beautiful; but when we regard it with microscopic attention, it seems a confused mass of yellow and blue parts, each particle reflecting but one separate colour: but very different is the colour of a prismatic ray; no art can make one of equal brightness, and the more closely we examine

mine it, the more simple it appears. To magnify the parts of this colour is but to increase its beauty.

AMIDST all the variety therefore in nature, there are but seven original colours; violet, indigo, blue, green, yellow, orange, and red. Of these simple colours, all the artificial ones, which we see every instant, are composed, and every object is of this or that colour, as its parts are fitted for reflecting the correspondent ray in greater abundance. A red object reflects the red rays most copiously, a blue object the blue, green objects reflect the green ray, and so of all the rest.

BUT though the colour of an object arises from its reflecting rays only of one particular colour, yet a number of parts may be so mixed in one object, as to reflect the rays of almost every colour in the prism, as we may easily effect by mixing different powders together, tho'

in this case, in reality, the colours are reflected from a great number of minute objects all of different hues, yet to our naked and undistinguishing eyes, the whole seems but one uniform surface of colouring. Thus we often call that green, which is in fact a mixture of blue and yellow; we think that orange, which is composed of two colours, yellow and red: and thus in general objects of different tints are made to imitate one of the original tints, granted by the simple prismatic ray; but colours, thus compounded, may be easily distinguished from the simple ones. That body, which reflects one prismatic colour in greatest abundance, has ever the most beautiful and the brightest dye; while, on the contrary, those bodies, which reflect several different colours, seemingly blended to the eye, ever strike us with less vivid and less beautiful impressions: and indeed, the whole secret in the painter and dyer's art, is to make their colours as simple as they can; for in proportion as they are mixed,
they

they lose their beauty ; for instance, the simple green prismatic colour is the most beautiful imaginable ; a green less beautiful is made by an artificial mixture of two colours, blue and yellow ; a green, still less beautiful, may be made by a mixture of simple green, orange, and indigo ; but the most obscure green of all will be that made by a still greater number of these colours united. By much composition in this manner, the beauty of every colour may be destroyed, and all its liveliness dimmed into faintness. Grey, russet, brown, are only compositions of many colours, they may be considered as so many lesser degrees of white, and differ only in having the proportion of their colours less evenly mixed, and consequently not affecting us with such strong sensations.

It was observed in the beginning, that the different colours passed through the prism in different directions. The red, being least refracted or bent in its course,

went almost directly forward; the succeeding colours diminished in their force, till the violet was refracted most of all, and went through the prism in a very oblique direction. What can be the cause of this more direct progress in one ray than in the other? Why is the violet driven more out of its course than the red? Can it be ascribed to any other cause than the different attractions which the different rays undergo from the medium, or glassy body, through which they pass? It must certainly be so. The red rays are least attracted, and therefore drive through most directly; the violet are most attracted, and therefore they go through the most oblique of all. We have often had occasion to observe, that almost all bodies repel as well as attract; and that when at a certain distance, the attracting power is too feeble to act, then the repulsive power exerts its force, and the bodies are driven separate. Now whatever be the attractive force of the prism upon some rays of light in some circumstances,

stances, it will have a repulsive force upon the same rays in other circumstances, and that ray which it attracted most strongly at one time, it will repel with the greatest violence at another. A ray repelled or driven back is only in other words a ray reflected, so that we may say, that those rays, which are most strongly refracted, are most strongly reflected also; the attractive power operates at one time and refracts the ray, and the repellent power at another, and reflects it. If this then be the case, the violet ray, as it is most refracted, will be most reflected also; while on the other hand, the red ray, as being small in refraction, will be slow in reflection; and this is found true by experiment: for if we turn a prism round upon itself in such a manner, that the light, which was transmitted through it, be reflected upon an object properly disposed, we shall see the violet will be the first colour that will suffer reflexion, then each other colour in succession, till red comes to close up the rear. From hence
therefore

therefore we may conclude, that the same cause, which produces the refraction of the rays, produces their reflexion also. The more we know of Nature, the more we discover her uniformity.

WE may now then universally conclude, that if colours have not that variety, the uninitiated observer would suppose, that they are but few, beautiful, and simple, yet still enough by their variety to give us all those pleasures which a mixture of them is sometimes apt to produce. Colours and sounds have something in them alike. There are seven notes in music, there are so many colours in the prism. The distance between each note is ascertained, a similar distance is also found between each coloured ray; but we must not from hence suppose that there is any real resemblance between sounds and colours; these are merely accidental similitudes, and their diversities are still more numerous; each note, for instance, may be divided into
many

many tones; each simple colour is indivisible. The combination of tones sometimes increases their beauty, on the contrary, the combination of colours deadens their effect. The succession of sounds have a very fine influence upon the mind, the succession of colours has scarce any: yet in this philosophical age, it was not to be supposed, that the trifling resemblance between sounds and colours, as mentioned above, should pass without proper notice. In fact, a whimsical French philosopher has written a treatise to prove, that as our ear finds pleasure in the succession of sounds, so the eye may have a similar one from the succession of colours. There is, says F. Castel, a music of colours as well as of sounds; and when the eye has been for a short time lessened to ocular succession, there will arise as much pleasure to the eye, as the ear derives from sound. For this purpose he composed an ocular harpsichord, as he called it, which, instead of sounding to the ear, presented colours to the eye: the prismatic rays furnished

furnished the notes, and the shades between were substituted for the semitones. The inventor however died without finishing an instrument, which raised the expectations of many, but excited the ridicule of more. Sounds furnish the ear with all its pleasure. Colours furnish the eye but with half its pleasures, for figure comes in for the other half. To make such an instrument satisfy the sense, the beauty of colour and figure must be united.

C H A P. X.

*Of the Figure and Disposition of the Sur-
faces of Bodies, to reflect their respect-
ive Colours.*

THE reader now perceives the cause of all colours, and knows that it is light, which, differently coloured itself, thus dresses them in various beauty. Each object sends back to our eye those rays of light, which its surface is best adapted to reflect. The ruby drinks up every other ray of light, the green, the blue, and the violet, but repels back the reddening rays to our eye in all their prismatic lustre. The amethyst imbibes the stronger rays, and gives back the violet with milder brightness. The tulip gives us only the yellow, and the hyacinth its vivid blue. Every coloured object may be thus regarded as a partial divider of the rays of light, as a prism which can only separate one colour, but confounds all the rest.

It

IT will be now a subject entirely curious, to inquire what is the peculiar conformation of those bodies, which thus reflect one sort of rays and no other; to assign the cause why the ruby reflects nothing but the red rays, and the hyacinth only blue.

WE have hitherto only observed the colouring substance itself, we ought now to consider the preparation of the ground which receives it: to inquire how it comes that every object hath this separative power over the particles of light; how it imbibes one colour, while it copiously reflects another?

THE reason in general, why bodies reflect this or that kind of ray more copiously than any other, and consequently assume one particular colour, is, that the size and density of the parts, of which bodies are composed, are different. Let us for a moment suppose the surfaces of all the objects around us composed of an infinite
2
number

number of small glassy plates, let us suppose too the plates of one surface something thicker than the plates of another; let us still farther suppose, that a beam of light, with all its seven rays, strikes against one of these little thin plates, what will be the consequence? This plate will in some measure resemble a shield: if it be extremely thin, it will be unable to repel the strongest darting rays. The red, the orange, the yellow, the green, the blue, and the indigo rays will all dart through it with unresisted force; the feeble violet ray alone will be unable to get entrance, and will therefore be reflected back to our eye, and we shall see the whole object, if it be composed of similar plates, of a beautiful violet colour, while all the other rays have passed into the substance of the body, and are there stifled and lost. Suppose the plate against which the seven rays are darted to be a little thicker, the indigo then will be repelled and reflected, and the object will appear of that colour; thus, as the
plates

plates increase in thickness, the colour will approach to redness, for the thickest plates of all will reflect only that colour; thus therefore the colours of bodies will depend upon the different thickness of the plates, of which their substance is composed. The thinner the plates, the body will be more inclining to violet; on the contrary, the thicker they are, it will then approach more nearly to redness.

BUT we have here supposed two things, which must be first proved. We have said that bodies are composed of small transparent plates, and we have asserted also that the thinner the plate, the more approaching to violet will be the colour. The first of these is obviously true, the parts of all bodies, though seemingly void of transparency, when viewed in the gross, will be found, if taken separately, to be pellucid like glass. Nothing can seemingly be more opaque and free from transparency than the clothes we wear, yet let us but examine any one of the woollen
hairs

hairs that go into their composition with a microscope, and it will be found nearly transparent. Gold in the mass lets no light through it, but if beaten out extremely thin, we shall then see that its parts are transparent like other bodies, and it will cast a greenish light if put over a hole in a darkened window; so that if gold be composed of transparent parts, we may safely conclude the same of all other bodies whatever.

THE second assertion, that the thinner the plates, the more inclining to violet or to black itself, would be the colour of the body which they composed, comes next in view. This, at first sight, seems impossible to be proved, for where shall we find plates sufficiently thin to determine this, or how can we measure them when found? Newton, the most fertile of all philosophers in expedients to confirm his theory, threw light upon the intricacy by a very obvious, though till then unregarded experiment. The bubbles

which children blow with a mixture of soap and water, or the froth that we often see standing upon the surface of a washing-tub, appeared to him capable of being turned to philosophical purposes; things overlooked by the rest of mankind are often the most fertile in suggesting hints. He blew up a large bubble from a strong mixture of soap and water, and set himself attentively to consider the different changes of colour it underwent from its enlargement to its dissolution. He in general perceived that the thinner the plate of water which composed the sides of the bubble, the more it reflected the violet-coloured ray; and that in proportion as the sides of the bubble were more thick and dense, the more they reflected the red; he therefore was induced to believe, that the colours of all bodies proceeded from the thickness and density of all the little transparent plates of which they are composed: but this was only conjecture; to bring the theory to greater certainty, it was necessary to measure the thickness

thickness of the plate of water which composed the bubble; but this was attended with some difficulty, for the bubble was itself of too transient a nature to admit of any experiments upon it. He now bethought himself therefore, that two glass plates might be made to approach so very close to each other, that if water were put between them, it could be pressed as thin as might be thought proper. For this purpose therefore, a glass, a very little convex, was placed upon a plain glass, by which means they touched only in the middle, while all the other parts were almost, but not quite touching, so that water, or even common air, being placed between them, was pressed to the greatest conceivable degree of minuteness. As the convexity of one of the glasses was known, their distance from each other at every point could be easily measured, and thus the thickness of the plate of water between them, at any distance from the center, where the glasses touched, might be de-

terminated with the most exact precision. When these glasses then were thus pressed together, the water or air between exhibited the following appearances: In the middle point, where they touch, appeared a black spot perfectly transparent, next to this a ring of blue, then of white, yellow, orange, red; then a new order of the same colours begins again, and soon, one coloured ring without the other, for six or seven different repetitions of orders successively, each outer circle however more obscure than those within, like the circular waves upon a disturbed sheet of water. In all the orders, however, it appears that the reds are reflected by the plates of greatest thickness, and the violets by the thinnest.

It must be observed, however, that the colours in these rings are by no means simple, but made up of two or three, and sometimes four of the simple prismatic colours united together; and from hence therefore we may infer, that
all

all the objects of nature may be supposed to have their tints compounded. Like these coloured rings, each object around us partakes of several simple colours blended into one composition, and by knowing the simple colours that go into the composition of a single ring, we may nearly conjecture the simple colours, that go into the composition of objects of exactly similar colours, with which we are ordinarily conversant. Thus, for instance, if we turn our eyes to the azure blue of the skies, and demand what are the simple colours that go into its composition, we have only to examine the different orders of blue in the variously coloured rings of this pleasing experiment: among the number, we find a beautiful faint blue of the first order, exactly resembling the colour of the serene sky: nor does it only resemble this blue in colour, but in nature also. The colour of the heavens must arise from the nearly transparent vapours that float within its bosom excessively small, and their parts of almost

inconceivable thinness; the blue coloured ring is reflected by a plate as thin as can well be imagined, being nearly an hundred thousand times thinner than the crystal of a watch. In this manner we may find the simple prismatic tints in every other object. The beautiful green of the fields exactly resembles a fine green in one of the coloured rings of the third order. This colour is compounded of three simple tints, blue, yellow, and green, and resembles the natural verdure of the fields in more than one circumstance; for as the vegetables wither, they grow yellow, and thus discover the colours which originally went into the composition of their natural beauty; in short, there is scarce a colour in nature, that we shall not find some shade in these coloured rings bearing some resemblance to; and universally, the less compounded every colour, and the more it approaches prismatic simplicity, the more vivid its appearance, and the more intense its ray.

LET

LET us again therefore repeat with unsatiated pleasure those surprising disquisitions into nature. Every object takes its colour from the rays of light, which its parts are most fitted to reflect. The small constituent parts of every object are in themselves transparent, and while they suffer some rays to pass, they reflect others. If the parts were extremely small, and composed of plates as thin as the sides of a bubble just going to break, their colour would be of the violet kind; if the parts were thicker, they would assume stronger colours through the successive shades up to red. Nature however presents us with no object, whose colour is simple and reflects only the light of a single coloured ray. The skies, the fields, the flowers, the emerald, and the ruby all have their tints from a composition of simple colouring, each most beautiful the nearer it approaches simplicity.

THUS far of the cause of colour and the size in the parts of bodies to reflect

it; but still a difficulty remains: How comes it that some bodies are transparent, while others of the same colour are perfectly dark, and let no rays of light pass through them? How is it that the ruby may be seen through, while a piece of sealing-wax is perfectly opaque? How comes it that the emerald lets the green ray, which falls upon one of its sides, dart through to the other, while the leaf of a plant lets no light pass through at all? In order to solve this question, it may be proper to ask another: If the ruby or the emerald were taken and ground into a powder, what would be the consequence? the consequence would certainly be, that neither would any longer be transparent, nor suffer the light to pass through them. The ruby thus powdered and made up into a paste, would be as opaque as the sealing-wax itself. The reason of this difference then will now be obvious: While the ruby was in its jewel state, its pores were small, and the plates of which it was composed lay evenly surface over surface, like one glass plate

plate laid upon another. The light therefore falling upon this even solid surface was attracted through without hindrance, and but few of its rays were driven back, or suffered reflection by the way; but it must be very different with the same body when reduced to powder; it then becomes porous, its surfaces lie confused and in unequal directions. A part of the rays of light therefore will fall upon the outward broken particles of the gem, and by being reflected to the eye, give us, as in the former case, a sensation of redness; but far the greater number of rays will pass into its substance, they will upon entrance find it porous, the condensed matter which in the former case attracted it, and increased the rays celerity, now no longer acts with equal force, the ray feebly attracted therefore will be partly repelled, will dart from pore to pore, will be driven into ten thousand directions, and will be at last totally lost to sense. In a word, the transparency of all bodies arises from
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the closeness and similitude in the texture of their parts, while their opacity on the contrary arises from their being very porous, or from being composed of parts very dissimilar to each other. The ruby was deprived of its transparency by being ground to a coarse powder, a degree of transparence might again be restored by grinding these coarse parts so as to make them extremely fine, and thus restore them in some measure to their original minuteness. And in this manner some of those transparent bodies, called paste, are formed by repeated trituration. We may conclude therefore that to make almost any body transparent, little more is requisite than to diminish the pores. Paper transmits but little light; it becomes more transparent by stopping up its interstices with oil.

As the parts of bodies must thus be close and similar when they are transparent, on the other hand, if they reflect light, this must necessarily come from
their

their pores. The ray, which is attracted by the solid parts of the body, is repelled when it comes to a pore; for wherever attraction ceases, there repulsion begins. Thus, when the rays of light pass from air into glass, just at their entrance into this new medium, some of them must meet pores, from which they will partly be repelled, and yet a part will enter, and so there is a small reflection from the nearer surface of the glass. As the rays go forward, by coming to the back surface of the glass, and going again out into air, they will meet with a greater number of pores than they first did upon their entrance into the glass, and there will be therefore more rays reflected from the back surface than from the nearer; and if the rays, instead of going out from the back surface into air, went into a void, which has still more pores than air, they would meet still more opposition to repel their progress, and they would be reflected in greater abundance. What is thus true in theory, is equally proved by
expe-

experience; for if we cover the mouth of a receiver with a glass properly disposed, then we shall see, as the air is pumped from behind, the rays will begin to be reflected from the hinder surface in a very copious manner.

IN this manner is light reflected from the pores of all bodies; but it may be objected, that we formerly asserted that the densest and thickest plates are those which reflect the most numerous rays, whereas we now say, that the pores reflect the rays only; does not this imply a contradiction? Not at all; for we must observe that a ray of light is ever most reflected when it passes between two mediums, which have the greatest difference in their densities: for instance; it is most reflected when it passes from a very rare medium, like air, into a very dense one, like quicksilver. It is repelled from the pores of the latter in great abundance; for quicksilver, though dense, hath numberless pores notwithstanding.

THIS

THIS then brings us to the last step of our theory. We said long since, that bodies which were very white reflected all manner of rays. Tin is such a body. We now say that the densest bodies are most apt to reflect rays coming from a rarer medium. Quicksilver has great density; a mixture of tin and quicksilver, therefore is made use of to reflect the rays in a common mirror. A transparent glass plate is fixed before to prevent any injury being offered to so soft a substance as the two metals united make; a part of the rays enter the pores of the glass, they go through, meet a medium of different density, part are reflected from its pores to our eyes, and part go to be lost irrecoverably in the bosom of the metal.

As the colour, transparency, and reflecting power of bodies in this manner arise from the different densities and thickneses of the parts of which they are composed, it is no way surprising to see

two

two liquors entirely changed by being compounded with each other; for whatever makes a change in the density of the parts of which either fluid is composed, will of consequence alter its transparency or its colour. If the saline parts of one liquor enter the pores of another, this will dilate them, and consequently alter their colour. If two liquors ferment, the parts of one will be dashed against those of the other, and thus either unite into larger masses, and so become opake, or break into smaller, and thus grow transparent. A few instances of such alterations in liquids will not be improper.

IF we infuse or steep the common gall-nut in water, and mix this with some powdered vitriol or copperas, it will make the black liquor, ink. If we pour into this mixture a few drops of aqua-fortis, the whole will then become as clear as water; for there is (if I may so say) a stronger affinity between the vitriol and aqua-fortis, than between the gall-water
and

and vitriol: the vitriol and aqua-fortis therefore attract each other, they unite, and the heavy aqua-fortis drags the vitriol with it to the bottom, leaving the gall-water above all in its former transparency. If now some drops of a lie of pot-ash be poured in; as the affinity between the aqua-fortis and pot-ash is greater than between aqua-fortis and vitriol, the aqua-fortis will desert the vitriol and cling to the pot-ash. It drags it down to the bottom, as it before did the vitriol, while in the mean time the vitriol being set free, again mixes with the gall-water, and thus the fluid assumes its former blackness. It may be again made transparent, by pouring in a few drops of the spirit of vitriol.

A SOLUTION of copper, which is green, is made clear like water by pouring in a few drops of spirit of nitre; and by again mixing some oil of tartar, it becomes green, as before.

RED

RED roses steeped for a short time in brandy gives a colourless liquor. Aqua-fortis, just slightly dropped in, gives the whole a beautiful red. A lie of pot-ash turns this to a beautiful green. Spirit of vitriol dropped in, after standing a few minutes, turns the liquor to red.

A TINCTURE of red roses is made black by a solution of vitriol, and becomes red again by oil of tartar.

SOLUTION of verdigrease, from a green, by spirit of vitriol becomes colourless, then by a spirit of sal ammoniac turns a purple, and then by oil of vitriol becomes transparent again.

THE following liquors, themselves void of colour, produce by mixture a highly coloured liquor. Rosated spirit of wine, quite limpid, and spirit of vitriol, almost so, produce a red. Solution of mercury and oil of tartar, orange. Solution of sublimate and lime-water, yellow.

low. Tincture of roses and oil of tartar, green. Tincture of roses and spirit of urine, a blue. A very slight solution of copper and spirit of sal ammoniac, purple. Solution of sublimat and spirit of sal ammoniac, white. Solution of saccharum saturni and solution of vitriol produce a black.

THE following liquors, which are coloured, being mixed, produce colours very different from their own. The yellow tincture of saffron, and the red tincture of roses, when mixed, produce a green. Blue tincture of violets and brown spirit of sulphur united, produce a crimson. Red tincture of roses and brown spirit of hartshorn make a blue. Blue tincture of violets and blue solution of copper, give a violet colour. Blue tincture of cyanus and blue spirit of sal ammoniac coloured make green. Blue solution of Hungarian vitriol and brown lie of pot-ash make yellow. Blue solution of Hungarian vitriol and red tincture of red roses make

a black. Blue tincture of cyanus and green solution of copper produce a red.

THESE liquors are mostly transparent, so that when a square flask is filled with any one of them, with blue solution of copper, for instance, we can see objects through its sides, all painted, as it would seem, with a beautiful blue. But need we by this time observe, that if two flasks of different coloured liquors be placed before the eye, no object whatsoever can be perceived through them? Need we observe in this case, that the blue rays passing through one liquor, will take a different course when they come to the other liquor, contained in the adjoining flask? The learner knows, without doubt, that the rays will be turned out of their former direction, they will suffer a different refraction, and will not give a thorough light through both.

IT only now remains to account for that difference of colour which the same object

object frequently exhibits in different situations: thus, the colour of a dove's neck in one position is green, and in another, purple. The plumage in a peacock's tail now appears red, then a dazzling green. Some silks, looked at directly, are purple, sidewise, they are red. Some liquors, as an infusion of *lignum nephriticum*, held between us and the light, seems blue, but opposite the light seems red or yellow. Whence comes this difference? It arises from a difference of density in the small plates of which those bodies are composed. In one position, some are adapted to reflect the rays, while others to absorb and transmit them; for if we suppose one of these double-coloured objects to be made up of two substances of very different densities, for instance, the particles of the body itself to be one substance, and the fluid that enters between them another, the reflections from these parts of very different densities must be very different at different obliquities of the eye. Let us

wet these double-coloured objects, let us dip the variegated feather in water, or the changeable silk in oil, the densities and thicknesses of their parts, and the fluid within them are rendered more alike, their reflection will be therefore less vivid, and they will return but one uniform shade of colouring.

YET perhaps all this may be accounted for on much more obvious principles. The small plates of colour in one position are turned to the eye, in another, they are turned away, and a different surface presented to the spectator. In the same manner in feeling; some sorts of stuff, such as common plush, if we draw the hand in one direction, will be a smooth surface, but in an opposite direction, very rough. The same object may thus present different surfaces to the eye, as well as the touch; as a field of corn, viewed with the wind, is of a different shade from the same field viewed against the wind; in each case, we see different parts
of

of the same object presented to the view. The more approaching to the testimony of our senses every philosophical solution is, the more perhaps is it conformable to nature. It is the business of a philosopher, like a parent, to correct the errors of sense, but not, like a tyrant, totally to reject their information.

C H A P. XI,

Of the Rainbow.

OF all the meteors which result from the reflection of light, the rainbow is the most pleasing and extraordinary: its colours not only delight the eye with the mildness of their lustre, but encourage the spectator with the prospect of succeeding serenity.

IT is but by slow and painful steps we arrive at the true causes of things: the colours of the rainbow, which struck antiquity with amazement, no longer now create the philosopher's surprise. To Pliny and Plutarch it appeared as an object which we might admire, but could never explain. The priests always preferred the wood on which the rainbow had appeared to rest, for the burning their sacrifices, vainly supposing that this wood

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had

had a perfume peculiarly agreeable to their deities. Some philosophers of the obscure ages began to form more just conceptions concerning this meteor; but Kepler it was, who first supposed that it might arise from the refraction of the sun's rays upon entering the rain-drops. Antonio de Dominis enlarged a theory but just hinted at by Kepler; and his treatise *De radiis lucis et iride* appeared in the year 1611, several years after the author himself had been driven from his bishoprick of Spalatro in Dalmatia by the Inquisition, for attempting to oppose the opinions of Aristotle, which were then closely connected with religion, or at least thought to be so. Each succeeding philosopher went on in improving a theory, the truth of which seemed to carry great probability. Cartesius and Mariotte both set themselves to improve the inquiry, but as they were ignorant of the true causes of colour, they left the task unfinished, for Newton to complete. The theory of the rainbow, as explained by

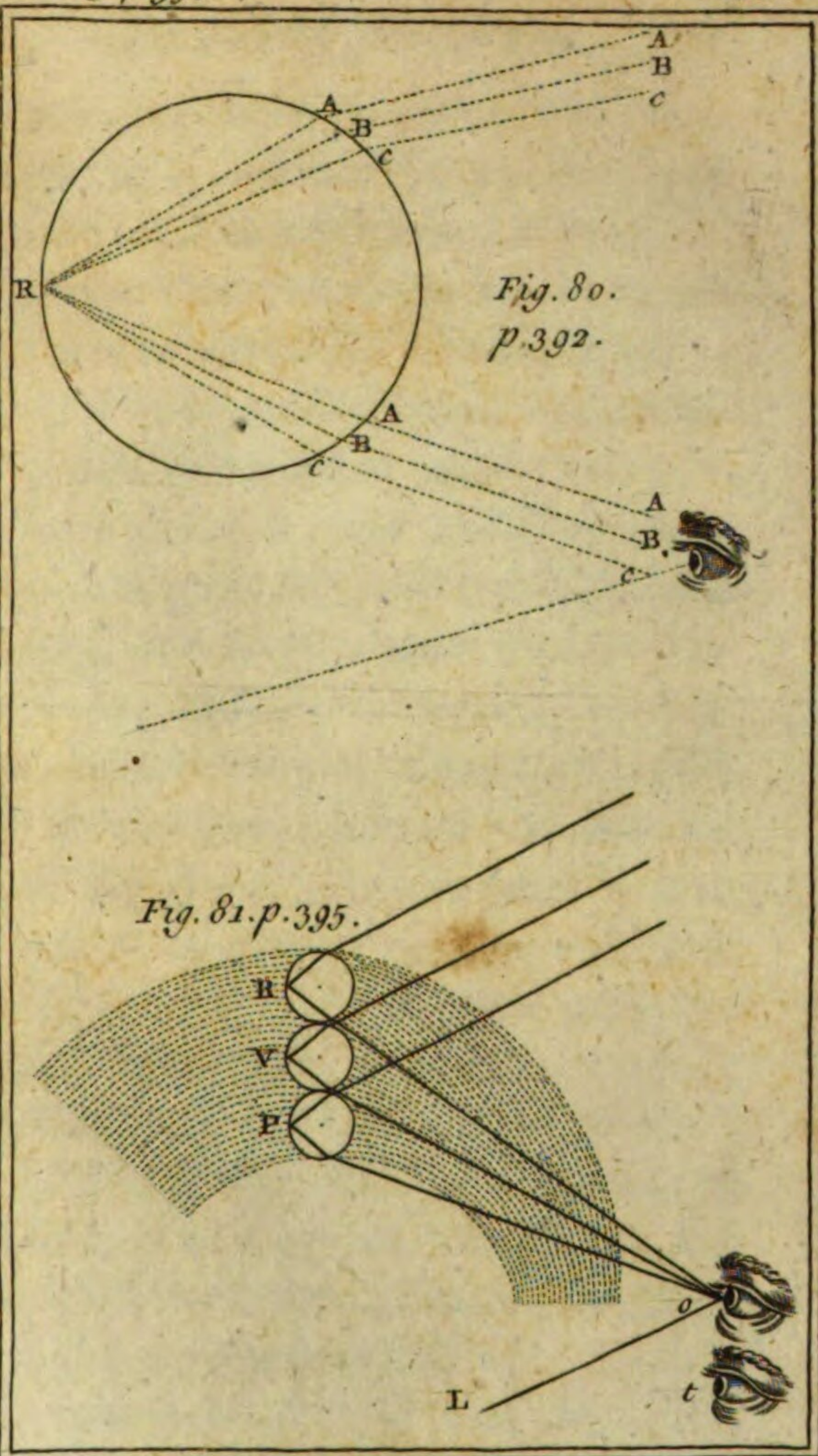
him, is full, clear, and impresses the mind with perfect conviction. Of all the various meteors which serve to terrify or amuse us, this is the only one, for which naturalists can account in a satisfactory manner.

It is needless to describe this meteor, which every reader must have surveyed with wonder. The most untutored spectator knows, that it is only seen when he turns his back to the sun, and when it rains on the opposite side. Its colours are, beginning from the under part, violet, indigo, blue, green, yellow, orange, red, so that we see it contains all the beautiful and simple shades of the prism. Without the first bow, we often see an external rainbow, with colours less vivid, and ranged in an opposite order, beginning from the under part, red, orange, yellow, green, blue, indigo, violet; sometimes we see half, sometimes an whole bow, frequently one, very often two, nay, three have been seen; Dr. Halley
gives

gives an account of his having observed such a triple bow at Chester, and many others have seen the same. Now then, to explain the manner in which the bow is made, and the cause of these various appearances, which it is found to assume,

LET us begin this theory with the experiment by which Antonio de Dominis undertook to explain the cause of the rainbow: this philosopher filled a glass globe with water, and hung it at a certain height, opposite the sun, then standing himself with his back to the sun and his face to the globe, he found, that when this was placed in such a situation, as that a ray darting from the sun to the globe made angle, with another ray going from his eye to the globe, of forty-two degrees three minutes, in such a case, I say, he found that the globe appeared red. If the globe was altered, so as to make the angle between the solar and the visual ray less, then the other colours of the rainbow arose, from red down to violet,

violet, which appeared at an angle of forty degrees seventeen minutes. Let us now suppose ourselves in this philosopher's place, the globe before us, the sun behind, and its rays against the globe making an angle with our visual ray of forty-two degrees three minutes: we know that millions of the sun's rays fall upon this globe, and that each ray has a different colour, and is differently refracted upon entering the globe, the red ray being least refracted, and the violet ray most of all. For this reason, the red rays will pass out of the globe in one place, the orange rays in another, the yellow, the green, the blue, the indigo, and the violet will all pass separately. To make this still plainer, let us suppose this globe an assemblage of an infinite number of plain surfaces, which it is in effect. (See fig. 80.) Let us suppose the red rays, A B C to come parallel from the sun upon three minute surfaces of the globe, now we know that each will be refracted or bent in passing into the globe proportionally



Proud Sculp.

proportionally to its angle of incidence. The red ray A falls with the most oblique incidence, and its refraction will be therefore greater than that of the ray B or C, so that it will be bent to R. The ray B comes with a less oblique incidence, and therefore it will be refracted more directly to the same point R; the ray C inciding still less obliquely than either, will be less refracted, it will go almost directly forward to R; thus the three rays, by falling at different angles of incidence, will unite in the same place at the opposite side of the globe. At the point R each ray will be in a great measure reflected, making an angle of reflection perfectly equal to the angle of incidence; from R, therefore, each ray will travel backward out of the globe, and upon emerging from thence at *a b c*, they will make the same angle with the surface of the globe as that by which they first entered, they will therefore all turn out parallel as they first came from the sun, and they will strike the spectator's eye, if it happens

pens to be placed conveniently, at *o*. If there be a sufficient quantity of these to affect the optic nerve, they will then be seen, and appear red. The rays *abc* are the visible ones of the globe or drop of water, and every drop of water has thus its visible rays. There are numberless others which do not come to the eye; there are millions of orange, blue, green, violet ones, which striking upon the same part of the globe with the red rays, that are differently refracted upon going through, and take a different road upon being reflected back, so as not to fall upon the eye placed at *o*. Were the globe lowered a little, and the angle thus made smaller, reduced to forty degrees seventeen minutes, then the violet rays would strike upon our eye, while the red rays we saw before would pass over our heads, and a spectator who looked over us would see them.

Now, what has here been said of one globe or drop of water is true of millions of

of drops. Let us imagine a shower falling at some distance before us, and the sun from behind us darting its rays upon the numberless drops of which it is composed. Let us, to avoid confusion, suppose we see a rainbow of three orders of colours; the drop R, that is seen at the largest angle, L O R, will be red, the drop seen at a smaller angle, L O V, will be green, and that seen at a still smaller angle L O P will be violet. (see fig. 81.) Thus, millions of drops will be seen of those three different colours: in short, all drops in that shower, seen at the same angles will appear variously coloured in that manner: all drops, I say again, that are placed between such angles, that is, of forty-two degrees and forty, will be seen coloured, and if so, we must thus see part of a beautiful circle of these colours; for we may readily suppose an arch in the heavens, every part of which shall be at an angle of between forty and forty-three degrees from the eye, and this arch is the rainbow. Our eye is in the point of a cone, and the rays that
2 dart

dart from it, falling at those angles, form the circular base of the cone: a part of this circle we see coloured, while the earth cuts off the other part which lies below our horizon.

To make this yet plainer; suppose the spectator were upon the top of a very high mountain, and the drops of rain falling near him, instead of a semicircular rainbow, he would then actually see a complete ring of that beautiful meteor. All drops at an angle of between forty and forty-two degrees will appear to him coloured. One drop may be supposed to be at that angle above the spectator's eye, another at the same angle downwards below his eye, one drop at that angle to the right, and another to the left; in short, we may thus complete a circle of drops, and this is that glorious circle which he sees, a circle not like our common bow, cut off by the earth, but completely beautiful, and usually seen from the American Andes.

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Fig 82. p. 397.

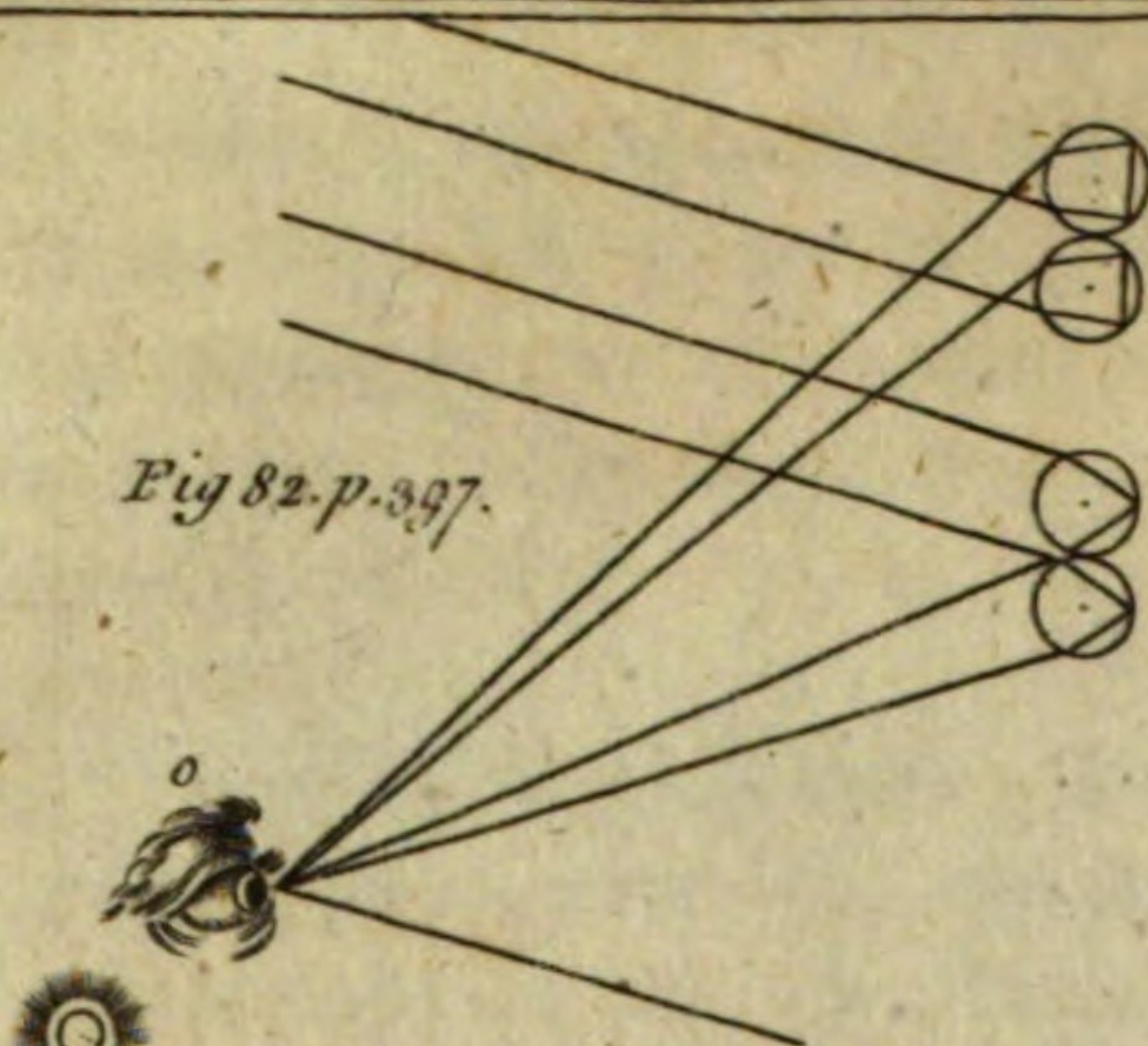


Fig 83. p. 398.

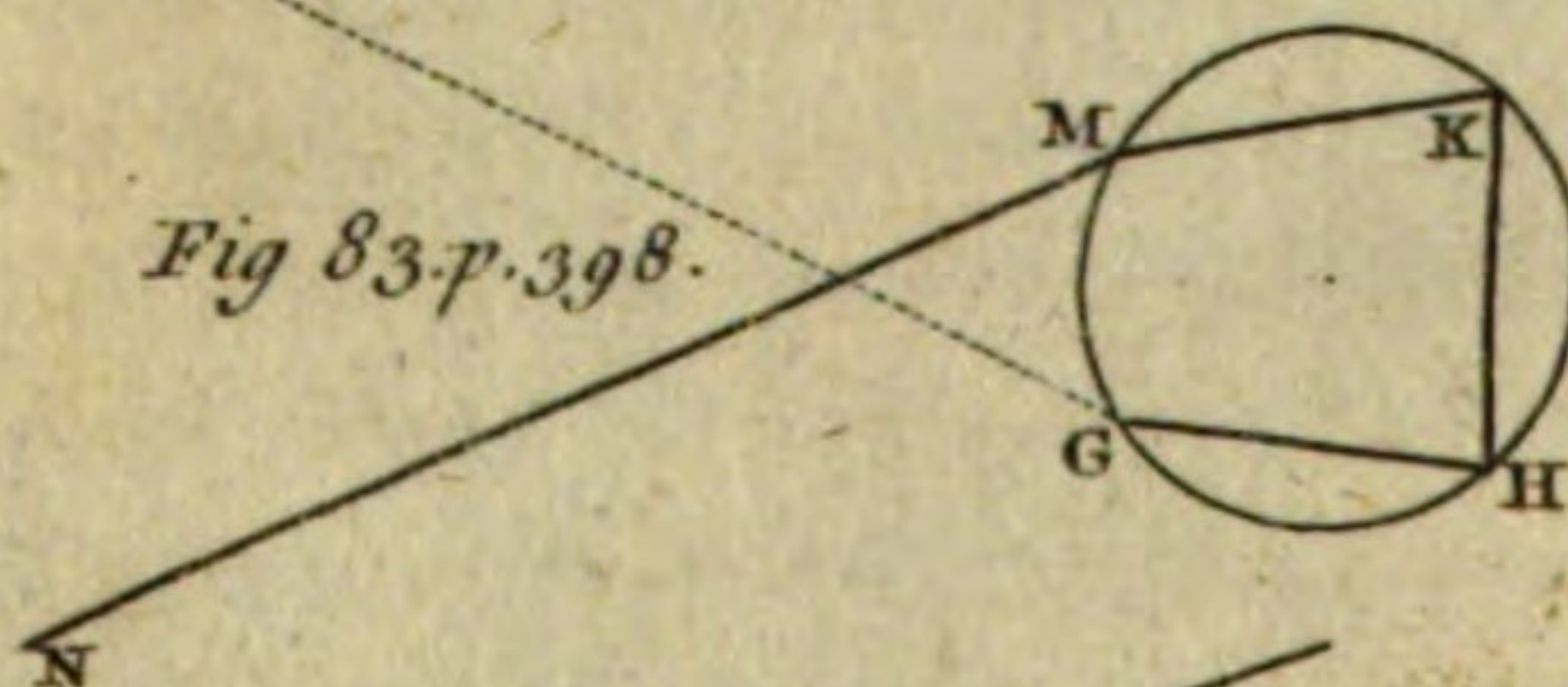
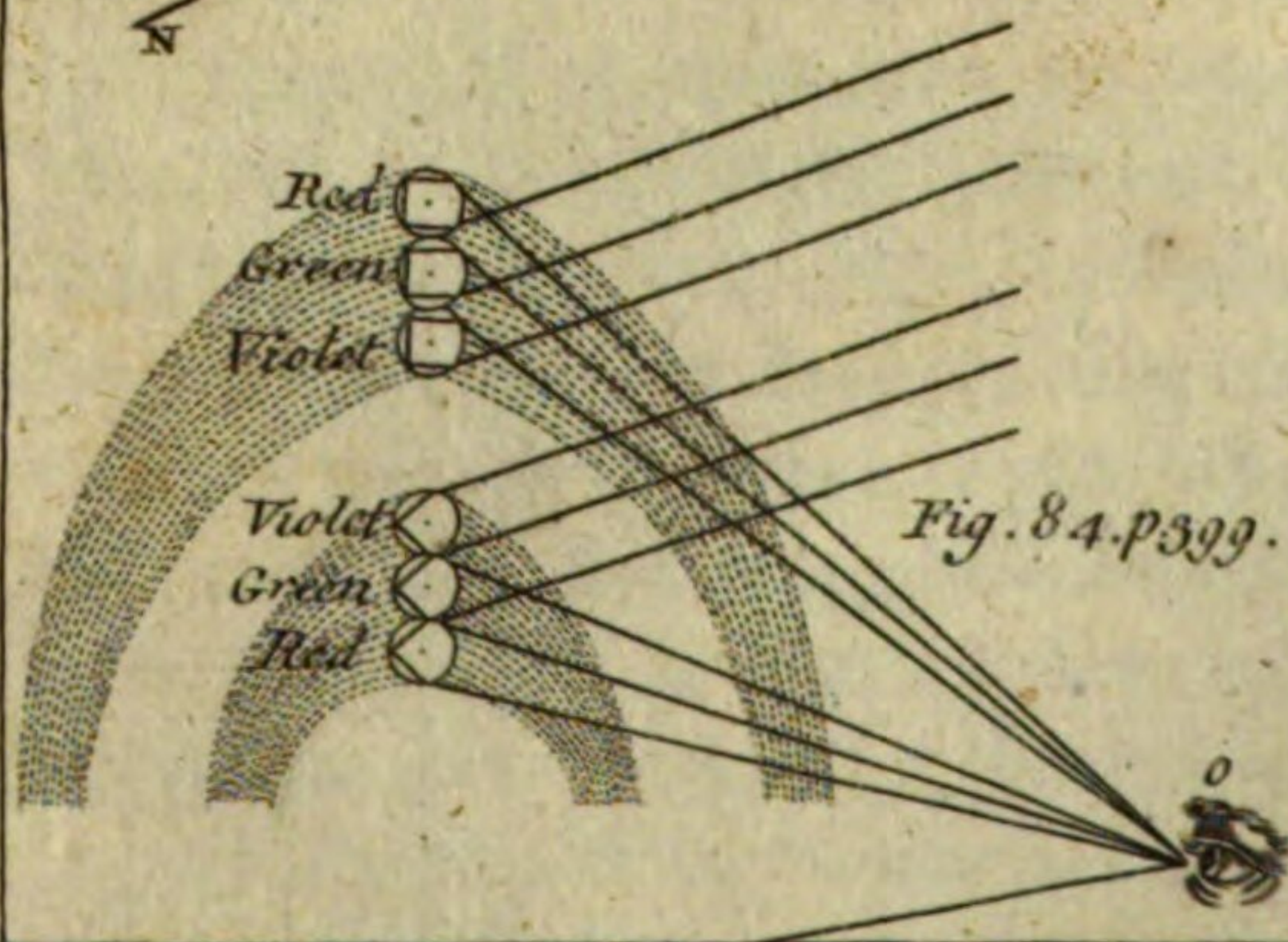


Fig. 84. p. 399.



Proud Sculp

WE come now to the second rainbow, which we observed encompassed the former, more widely spread, more faintly luminous, and with inverted colouring. This bow, like the former, is made by the rays of the sun darting upon the drops of falling rain, and from thence reflected to the spectator's eye. The difference between the two bows is this, that in the internal bow each drop receives the rays of the sun on its upper surface, (see fig. 82.) whereas, on the contrary, in the great external bow, each drop receives the sun's rays at its bottom, from whence the ray being twice refracted and twice reflected, it comes to the spectator's eye with diminished lustre and in an inverted order. But before we explain this, it must be observed, that as in the former bow experience proved that the drop must be placed at angles of between forty and forty-two degrees to transmit and reflect the coloured ray, so experience likewise proves, in the present case, that the drop must be placed at
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an angle of between fifty degrees fifty-seven minutes, and fifty-four degrees seven minutes, to appear coloured after two refractions and two reflections, which we shall now see a ray, passing through it, undergoes.

A BUNDLE of rays dart from the sun on the lower surface of the drop at G; (see fig. 83.) there a part of these enter, while another part is struck back by reflection, and lost: thus there is already part of the rays scattered and lost to the eye. The part refracted go on to H, a part of these go forward into air, and are thus lost again to the eye, while the little that remains is reflected up to K. Here a third time another part of the ray escapes out of the drop, while what remains is refracted to M; at its going out of the drop here, still another part of the ray is scattered and lost, which is a fourth diminution; lastly, what remains after so many diminutions is reflected to the eye at N. Thus the ray
comes

comes to the eye after no less than two reflections and two refractions; by this means, therefore, it loses near one half more lustre than is seen in the inner bow, where there is but one reflection only; and the colours also of this bow must come to the eye in a different order from those of the inner bow; for the eye being placed at O, (see fig. 84.) it receives the least refracted red rays from the outer edge of the internal bow, and it must therefore receive the most refracted or violet rays from the inner edge of the external bow, the violet ray *b* being much more refracted than the red ray *a*, as we see by the figure.

SUCH is the nature of this meteor formed by the solar rays; but there is sometimes also a lunar rainbow, formed exactly in the same manner, by the bright beams of the moon striking upon the bosom of a shower. This meteor Aristotle boasts himself to have first remarked, and assures us, that in his time

such a rainbow was seen, with the colours extremely lucid. Similar meteors have been frequently observed since his time; and, among our own countrymen, Mr. Thoresby has given the description of one in the Philosophical Transactions. The lunar rainbow which he observed was equally admirable both for the beauty and the splendor of its colours: it lasted ten minutes, till at length a cloud came and intercepted the view.

BUT we must take especial care not to confound this appearance caused by the moon, with that lucid ring which we often see diffused round it, called an Halo, for the production of which philosophy has as yet found no probable solution. Huygens supposes that there are certain globules in the atmosphere, consisting of a transparent shell of ice or water, but perfectly opaque within; and that from the partial reflections of these arises this meteor. This can give us but very little satisfaction in our research. An infinite number

number of drops with icy coats and opake kernels is a greater wonder than the Halo itself; we must therefore leave this meteor, with some others, such as the Parhelia, or mock-suns, the Paraselenae, or mock-moons, which so often appear in the regions round the north pole, quite unaccounted for. No illustrations are better than false illustrations. The rainbow is the only meteor for which we can clearly account; and it is thus, that while philosophy excites man's pride on one hand, it generally serves to mortify his presumption on another.

C H A P. XII.

Of adventitious Colours.

WE have hitherto considered colour as it is in the light, and as every object is peculiarly adapted for separating its different rays: we must now observe, that there are often colours in the eye itself, which alter the tints of objects contrary to our desire; we often see things peculiarly tinged, when we know their colour to be different from what it appears. To a jaundiced person, white objects seem yellow; for the humours of his eye are then actually tinged with that colour. To a person in a fever, the same objects appear red, from some similar alteration: thus, a change in the organ ever makes a seeming change in the object, so that we may now assert, that the colour is properly neither in the object, nor in the colouring ray, but in the

the mind, which perceives either. If the eyes of all men were naturally jaundiced, all white objects would appear uniformly yellow.

A QUESTION of a very intricate nature now therefore arises. Do all men see the same objects of the same colour? Do those fields which strike me with an idea of green, present a similar green to the friend with whom I am walking? we both, it is true, conspire to call that beautiful verdure by one name, yet may it not affect him with the same sensation which I receive from red, or any other colour? To make this plainer, suppose his eye were jaundiced from the birth, then it is evident that green would appear to him yellow; yet though we are sure he saw the colour wrong, yet this would cause no error either in his own ideas, or his conversation; for he would still continue to call that yellow colour green, and we should understand him very readily. If a great part of mankind

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had their eyes thus tinctured, each would see objects different from his fellow, yet none would be sensible of the mistake. I say then again, May not different men have different ideas of the same colour? I am apt to think their ideas are different. If two men look at the same shining spot of red upon a white wall for some time steadily, the colour will seem to alter to each, and new colours will arise. These adventitious colours, however, which the spot seems to assume, are different to different persons: the spot turns to blue in my eye, while it becomes green to the eye of another spectator that observes it with me. Now, if we had both originally seen the red spot of the same colour, we should see the changes it underwent of the same colour also; for if two things are exactly alike, similar operations upon them will produce similar effects. But in the present case, two different effects, two different colours are produced to each spectator from observing the same object, a proof that the cause which produced
7 this

this difference must also be double, or that the red spot excited two different ideas originally.

HOWEVER this be, the theory of adventitious colours, or colours which arise when the organ is intensely exerted, is a new and a pleasing subject: it was first started by Dr. Jurin, whom more than once we have had occasion to mention with respect. It was pursued by Monf. Buffon, and he has given the history of his particular sensations in this pursuit very accurately; every spectator may readily compare them with his own, and thus discover how far his organs of vision resemble those of others. I have tried the experiment with regard to myself, and have found the colours change to my view in a very different order from that in which they appeared to the French naturalist; the changes as seen by him are thus related:

WHEN a red spot upon a white ground is earnestly regarded for some time, a
kind

kind of green bordering is observed round the spot, and if the eye be taken off from the spot, and thrown upon another part of the wall or ground, it still continues to see a green bordering as before, approaching a little towards blue.

IF, says he, we observe fixedly and for a long time a yellow spot upon a white ground, we see the spot at length begin to be bordered with a pale blue, and if we avert our eyes towards another part of the white ground, we shall distinctly see a blue spot of the size and figure of the yellow one observed before.

IF we observe stedfastly and for a long time a green spot upon a white ground, we shall see a bordering of lightish purple, and in averting the eye, we shall see a purple spot of the dimensions of the former.

IF we observe in the same manner a blue spot upon the same ground, we shall see a bordering of white inclining to red-

ness, and averting our eyes, we shall see a spot of a light red.

If we observe attentively a black spot upon a white ground, we shall see a bordering of bright white, and turning to another part of the wall, we shall see a spot of exactly the same dimensions with the former of a whiteness far exceeding that of the wall.

If we observe long and attentively a square spot of bright red upon a white ground, we shall first begin to see the slight green bordering mentioned above; continuing to look with fixed attention, we shall see the middle of the square begin to be discoloured, and the sides assume a deeper red, and forming a square of a dark crimson; then retiring a little backwards, still keeping our eye fixed, we shall see the crimson edge or square cross the spot, and appear in the manner of a sash-window with four panes of glass, the cross bars in this little square being as visibly different as the wood from the glass

glass in the window; continuing still to look stedfastly and with perseverance, this cross changes again, and we see only a right angle of a red, so strong and penetrating, that it entirely dazzles the eye, and the organ becomes incapable of bearing further fatigue. If now the eye be turned upon another part of the white wall, the right angle will still appear, but no longer red, but of a bright and luminous green. This impression remains a long time, its colours fade away slowly, and even remain after the eye is shut.

WHAT thus is effected by regarding the red spot, will also be the consequence of our regarding a yellow, a green, a blue, or black spot, the cross and the right angle will successively appear each of a colour which is peculiarly adventitious to itself.

AFTER looking at the sun as long as the eye could bear, the image of this luminary was so strongly imprinted, that
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it mixed itself with every object that was viewed for some time after, in a manner resembling what has been already related.

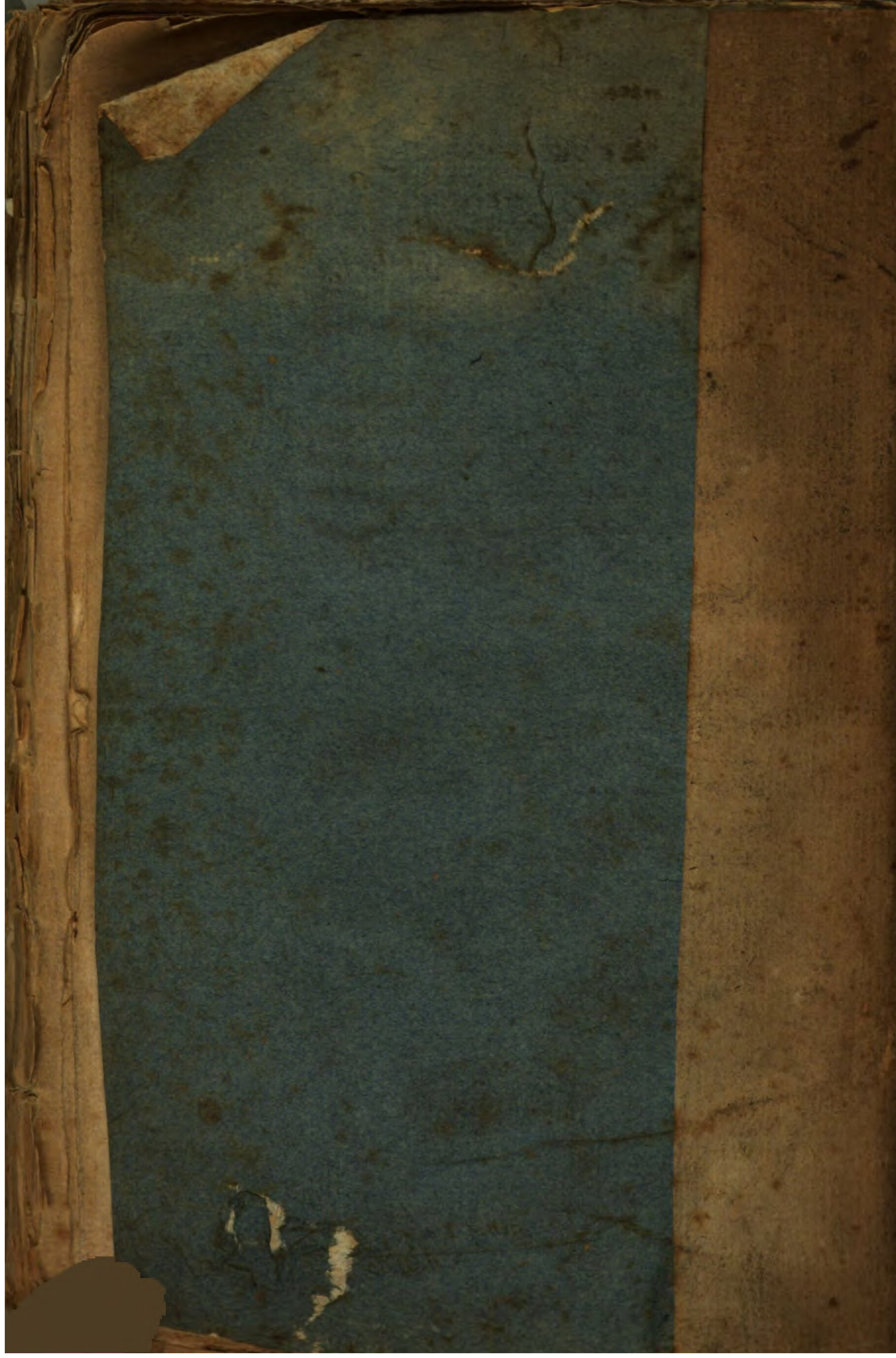
SUCH is the history of *Monf. Buffon*. It now remains to be observed, that in whatever manner it may in general describe the sensations of some eyes, it certainly does not agree with the changes which are wrought in all. The experiment is easy; and every spectator may be soon convinced, that the adventitious colours here described will not be exactly similar to those deduced from his own experience. What then can we gather from this inquiry? Only this, That colour is in the organ, not in the body seen: that man often makes colours without an object: that adventitious colours are not the same to every eye; and as these arise different, so it is very probable that the original colours, which are the sources from whence the others proceed, are also different: in other words, that the sensations which different men have from the same coloured object are as much diversified

verified as the organs that view them; and that not the things but the names are all that we can argue upon with certainty.

It is a conclusion sufficient to mortify reasoning pride, that the more minutely we penetrate into nature, the more we find cause to distrust our guide itself: that the deeper science is pursued, the more it serves to disenchant those pleasing delusions which itself had before taught us to fancy. A minute investigation of nature still presents new wonders, till at last, the philosopher seeing the number rise upon him on every side, each equally amazing and equally inscrutable, he at length loses curiosity in despair, and wonders at nothing: yet let us while we live strive to be amused and to amuse each other. If our happiness hereafter is to consist in knowing much, let us here, by our feeble anticipation at least, shew a passion for the enjoyment of scientific felicity.

F I N I S.

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